OUKA
The University of Osaka
Institutional Knowledge Archive

Title	STUDIES ON SELECTIVE REACTIONS USING HIGHLY COORDINATED ORGANOTIN COMPOUNDS
Author(s)	安田, 誠
Citation	大阪大学, 1995, 博士論文
Version Type	VoR
URL	https://doi.org/10.11501/3100634
rights	
Note	

The University of Osaka Institutional Knowledge Archive : OUKA

https://ir.library.osaka-u.ac.jp/

The University of Osaka

STUDIES ON
SELECTIVE REACTIONS USING
HIGHLY COORDINATED ORGANOTIN COMPOUNDS

MAKOTO YASUDA

Faculty of Engineering
Osaka University
1995

STUDIES ON SELECTIVE REACTIONS USING HIGHLY COORDINATED ORGANOTIN COMPOUNDS

高配位化有機スズ化合物を用いた選択的反応に関する研究

MAKOTO YASUDA

安田　誠

Faculty of Engineering
Osaka University

1995

Preface

The work of this thesis has been performed (1989-1995) under the guidance of Professor Haruo Matsuda and Professor Noboru Sonoda at Department of Applied Fine Chemistry, Faculty of Engineering, Osaka University.

The author would like to express his sincerest gratitude to Professor Haruo Matsuda for his sincerest guidance, helpful suggestion and hearty encouragement throughout this work. He retired at 1993, and since then has been a Professor in Department of Applied Chemistry, Osaka Institute of Technology. The author is deeply indebted to Professor Noboru Sonoda for his sincerest guidance, helpful comments and suggestions.

The author also wishes to make a grateful acknowledgement to Associate Professor Akio Baba for his intimate guidance, continuous advice, kind encouragement and stimulating discussions.

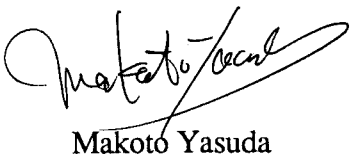
The author is grateful to Dr. Ikuya Shibata for his helpful suggestion and variable discussions. The author gratefully acknowledges invaluable assistance of Associate Professor Ryoki Nomura at Department of Applied Chemistry, Osaka Institute of Technology. Much thanks are given to Dr. Masahiro Fujiwara, Dr. Katsunori Yano for their continuous advice and encouragement.

Furthermore, the author wishes to thank Mr. Tatsuhiro Oh-hata, Mr. Yasuhiro Katoh, Mr. Tatsuya Fujibayashi, and Mr. Shoki Tsuji for their active collaboration. The author also wishes to acknowledge to all the members of Matsuda Laboratory for their hearty encouragement and constant assistance.

The author is particularly grateful to his betrothed, Kazuko for her hearty encouragement and understanding.

Finally, the author would like to express his thanks to his parents Kozo Yasuda and Fumiko Yasuda for their perpetual support.

Suita, Osaka
January 1995



Makoto Yasuda

List of Publications

(1) Change of Regioselectivity in the Reaction of Tin Enolates and α-Bromo Ketones; Synthesis of 1,4-Diketones under Non-radical Conditions
Akio Baba, Makoto Yasuda, Katsunori Yano, Ikuya Shibata, and Haruo Matsuda
J. Chem. Soc., Perkin Trans. 1, **1990**, 3205-3207.

(2) Facile Control of Regioselectivity in the Reaction of Tin Enolates with α-Halogeno Carbonyls by Additives
Makoto Yasuda, Tatsuhiro Oh-hata, Ikuya Shibata, Akio Baba, and Haruo Matsuda
J. Chem. Soc., Perkin Trans. 1, **1993**, 859-865.

(3) Chemoselective Coupling of α-Bromo Aldehydes with a Tin Enolate Derived from the Ring Opening of Diketene by Bis(tributyltin) Oxide
Makoto Yasuda, Masahiro Nishio, Ikuya Shibata, Akio Baba, and Haruo Matsuda
J. Org. Chem., **1994**, *59*, 486-487.

(4) NMR Studies of Five-Coordinate Tin Enolate: An Efficient Reagent for Halo Selective Reaction toward α-Halo Ketone or α-Halo Imine.
Makoto Yasuda, Yasuhiro Katoh, Ikuya Shibata, Akio Baba, Haruo Matsuda, and Noboru Sonoda
J. Org. Chem., **1994**, *59*, 4386-4392.

(5) Highly Stereoselective Addition of Tin Enolate to α-Chloro Cyclic Ketone Derivatives Catalyzed by Ph_4SbBr

Makoto Yasuda, Tatsuhiro Oh-hata, Ikuya Shibata, Akio Baba, Haruo Matsuda, and Noboru Sonoda

Tetrahedron Lett., **1994**, *35*, 8627-8630.

(6) A Catalytic Effect of Five-Coordinate Organotin Bromide or Tetraphenylstibonium Bromide on Chemo- and Stereoselective Addition of Tin Enolate to α-Halo Ketone

Makoto Yasuda, Tatsuhiro Oh-hata, Ikuya Shibata, Akio Baba, Haruo Matsuda, and Noboru Sonoda

Bull. Chem. Soc. Jpn., in press.

(7) Chlorotrimethylsilane-Acetonitrile System as a New Promoter for Carbonyl Allylation by Diallyldibutyltin

Makoto Yasuda, Tatsuya Fujibayashi, Ikuya Shibata, Akio Baba, Haruo Matsuda, and Noboru Sonoda

Chem. Lett., in press.

Contents

General Introduction

Organotin compounds are widely used in chemo- or stereoselective reactions owing to their appropriate stability and reactivity.[1] In most cases, the activation of electrophile by Lewis acids or the generation of reactive species by transmetallation are required in an ionic reaction of tin compounds, though they are often used under radical conditions. One of the most representative organotin compounds is a tin enolate, which is more reactive than the corresponding enol silyl ether, and adds readily to a carbonyl group in aldehydes or cyclohexanones without any assistance by Lewis acids.[2] On the other hand, the reaction with acyclic ketones or organic halides is very sluggish.[3] The assistance by such strong Lewis acids as $TiCl_4$, $SnCl_4$, and BF_3 often encounters undesirable side reactions like transmetallation, isomerization, and others. Therefore a milder and characteristic activation method of organotin compound is now desirable. The author has focused on the high-coordination ability of tin atom, whose stable coordination number is four. It can be expected that the increase of coordination number of tin atom would cause the change of reactivity and/or selectivity of tin compounds.

α-Halo ketones are important compounds in organic chemistry and show the variety of reactivities; for example, (1) carbonyl addition,[2,4] (2) halide substitution,[5] or (3) α-hydrogen extraction. In most cases, it is very difficult to predict which type of reactions will occur on treatment of an α-haloketone with a nucleophile. We now investigate on highly coordinated tin compounds.

The present research aims to the control of selective reactions using highly coordinated organotin compounds. This thesis consists of four chapters.

Chapter 1 deals with the facile control of regioselectivity in the reaction of tin enolates with α-halo ketone or halo ester by addition of Lewis bases such as HMPA and Bu_4NBr.

Chapter 2 refers NMR studies of five-coordinate tin enolate generated by the addition of HMPA to four-coordinate one. The five-coordinate tin enolate is proved to be

an efficient reagent for halo selective reaction toward α-halo ketones or α-halo imines.

Chapter 3 describes a catalytic effect of five-coordinate organotin bromide or tetraphenylstibonium bromide on chemo- and stereoselective addition of tin enolate to α-halo ketones. These two types of compounds show a similar catalytic activity owing to their structural and bonding analogy.

In chapter 4, chlorotrimethylsilane-acetonitrile system promotes the carbonyl allylation by diallyldibutyltin as a new promoter. Effective syntheses of homoallyl silyl ethers are accomplished.

References

1. (a) G. Wilkinson ed. *Comprehensive Organometallic Chemistry*; Pergamon Press: Oxford, 1982; Vol. 2, p 519. (b) M. Pereyre, J. -P. Quintard and A. Rahm, *Tin in Organic Synthesis*; Butterworths: London, 1987. (c) P. G. Harrison ed. *Chemistry of Tin*; Blackie: Glasgow, 1989.
2. (a) J. G. Noltes, H. M. J. C. Creemers, and G. J. M. Van Der Kerk, *J. Organomet. Chem.*, **11**, 21 (1968). (b) S. S. Labadie and J. K. Stille, *Tetrahedron*, **40**, 2329 (1984).
3. Y. Odic and M. Pereyre, *J. Organomet. Chem.*, **55**, 273 (1973).
4. (a) Y. Yamamoto, H. Yatagai, and K. Maruyama, *J. Chem. Soc. Chem. Commun.*, **1981**, 162. (b) K. Kobayashi, M. Kawanishi, T. Hitomi, and S. Kozima, *Chem. Lett.*, **1983**, 851.
5. (a) M. E. Jung and R. B. Blum, *Tetrahedron Lett.*, **43**, 3791 (1977). (b) M. Kosugi, I. Hagiwara, T. Sumiya, and T. Migita, *Bull. Chem. Soc. Jpn.*, **57**, 242 (1984). (c) M. Kosugi, I. Hagiwara, and T. Migita, *Chem. Lett.*, **1983**, 839. (d) M. Kosugi, M. Koshiba, A. Atoh, H. Sano, and T. Migita, *Bull. Chem. Soc. Jpn.*, **59**, 677 (1986).

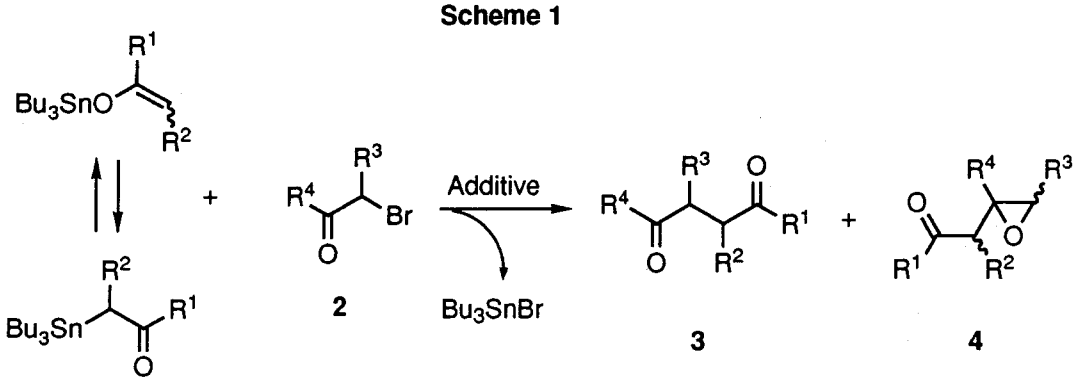
Chapter 1

Facile Control of Regioselectivity in the Reaction of Tin Enolates with α-Halo Carbonyls by Additives

1-1 Introduction

The reaction of organic halides with tin enolates has been studied as a means of carbon-carbon bond formation.[1] When α-halo ketones **2** are used as electrophiles, this reaction might provide a route to 1,4-diketones,[2] but addition to the carbonyl moiety of **2** is the usual reaction in the presence of Pd-catalysts, yielding the β-keto oxiranes.[3] The formation of 1,4-diketones has been limited to bulky or aryl substituted halo ketones using Pd or Ru-catalysts.[4] Moreover, acyclic α-halo esters give γ-keto esters in low yields in contrast to the effective coupling of α-halo lactones.[5] Various 1,4-dicarbonyl compounds are formed in a radical manner by the use of α-(phenylseleno) in place of α-halo carbonyl compounds.[6] Thus direct substitution reactions of α-halo carbonyls with tin enolates affording 1,4-dicarbonyls have not been accomplished.

Scheme 1



	R^1	R^2		R^3	R^4
1a	Me	H	**2a**	H	Ph
b	Me	Me	**b**	Me	Ph
c	$-(CH_2)_4-$		**c**	H	Et
d	Ph	H	**d**	H	*p*-MeO-C_6H_4
			e	H	*p*-Cl-C_6H_4
			f	H	Bu^t

We have already reported that Sn-heteroatom bonds were activated by coordination of ligands such as phosphine oxides.[7,8] Coordination using hexamethylphosphoric triamide (HMPA) is found to applied to the reaction of tin enolates with α-halo ketones, yielding 1,4-diketones, as briefly reported. In addition, we find that acyclic α-halo esters can be used as electrophiles yielding γ-keto esters.

1-2 Reaction of Tin Enolate with α-Halo Ketone

Table 1 exemplifies the predominant formation of 1,4-diketones **3** from tin enolates **1** and α-bromo ketones **2** in the presence of HMPA. These results contrast with the uncatalysed reaction and the catalysed by Pd complexes in THF under reflux which give β-keto oxiranes.[3] The addition of such Lewis bases as HMPA, Bu_3PO and Bu_4NBr, however, afforded good yields of 1,4-diketones **3**. With primary α-bromo ketones, the addition proceeded exothermically at ambient temperature. The use of 1.5 molar equivalents of HMPA with the tin enolate **1a** was effective giving the 1,4-diketone **3aa** (73%) from **2a** (entry 1). Excess of HMPA (5.0 equiv) depressed the formation of **3aa**, but higher selectivity was observed (entry 2). The use of less HMPA (0.1 equiv) resulted in a lower selectivity (Entry 3), with a higher yield of the oxirane **4aa** than in Entry 1. These results suggest that pentacoordinate tin enolate complexes give predominantly 1,4-diketones.

HMPA and Bu_3PO were effective in the reaction of **1a** with **2a**, while Et_3N and Bu_3P were not. The reaction of a secondary α-bromo ketone **2b** required heating at 80 °C for a good yield of **3ab** (Entry 8). On the other hand, Bu_4NBr gave **3** in higher yields and selectivities than HMPA even at ambient temperature (Entries 10, 13 and 22), where a pentacoordinate complex (ate complex) might also be formed by coordination of the bromide anion to the tin centre. Thus various substrates could be adapted to our method, giving the corresponding 1,4-diketones by a choice of an appropriate additives. *p*-Methoxy-2-bromoacetophenone **2d**, which has an electron-donating group reacted with **1a** to give 1,4-diketone **3ad** exclusively. However, *p*-chloro-2-bromoacetophenone **2e**

was less selective (entry 16). 1-Bromopinacolone **2f** required a longer reaction time, but the corresponding 1,4-diketone **3af** was obtained selectively in 79% yield. Tin enolates **1a-d**, of either keto or enol types,[9] can be used in this reaction.

Table 1 Reaction of tin enolates **1** with α-bromo ketones **2**

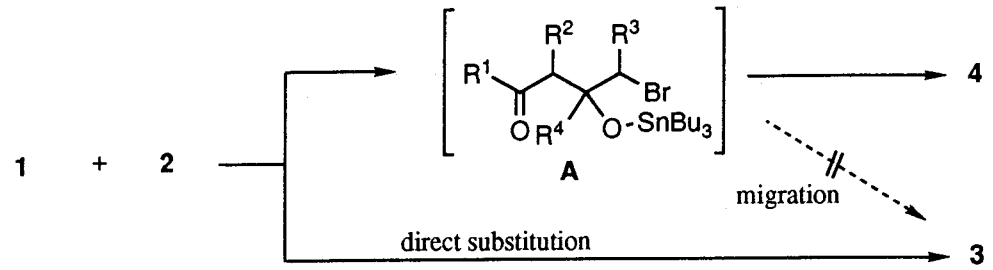
Entry	Enolate	Bromo ketone	Additive	T/°C	Time/h	Products (yield%)[a]
1	**1a**	**2a**	HMPA	25	1	**3aa** (73), **4aa** (12)
2			HMPA (5.0 equiv)	25	1	(33), (0)
3			HMPA (0.1 equiv)	25	1	(21), (17)
4			—	80	3	(0), (90)
5			—	25	1	(0), (0)
6			Bu_3PO	25	1	(48), (13)
7			Bu_4NBr	25	2	(40), (9)
8		**2b**	HMPA	80	1	**3ab** (89), **4ab** (tr)
9			HMPA	25	2	(24), (tr)
10			Bu_4NBr	25	2	(55), (tr)
11			—	80	24	(0), (76)[b,c]
12		**2c**	HMPA	25	1	**3ac** (54), **4ac** (44)
13			Bu_4NBr	25	1	(75), (10)
14		**2d**	HMPA	25	3.5	**3ad** (67)
15			Bu_3PO	25	1	(78)
16		**2e**	HMPA	25	3	**3ae** (35), **4ae** (28)
17			—	80	15	(0), (66)
18		**2f**	HMPA	25	7	**3af** (79)
19	**1b**	**2a**	HMPA	25	1	**3ba** (64), **4ba** (12)
20	**1c**	**2a**	HMPA	25	1	**3ca** (56), **4ca** (0)
21			Bu_3PO	25	1	(76), (0)
22			Bu_4NBr	25	1.5	(76), (0)[b]
23	**1d**	**2a**	HMPA (3.0 equiv)	25	21	**3da** (55) [d]

[a] GLC yield. [b] ^1H NMR yield. [c] E/Z = 27/73. [d] Oxirane was not detected because of its transformation to furan derivative (S. Padmanabhan, T. Ogawa and H. Suzuki, *Bull. Chem. Soc. Jpn.*, 1989, **62**, 2114).

1-3 Mechanistic Investigation

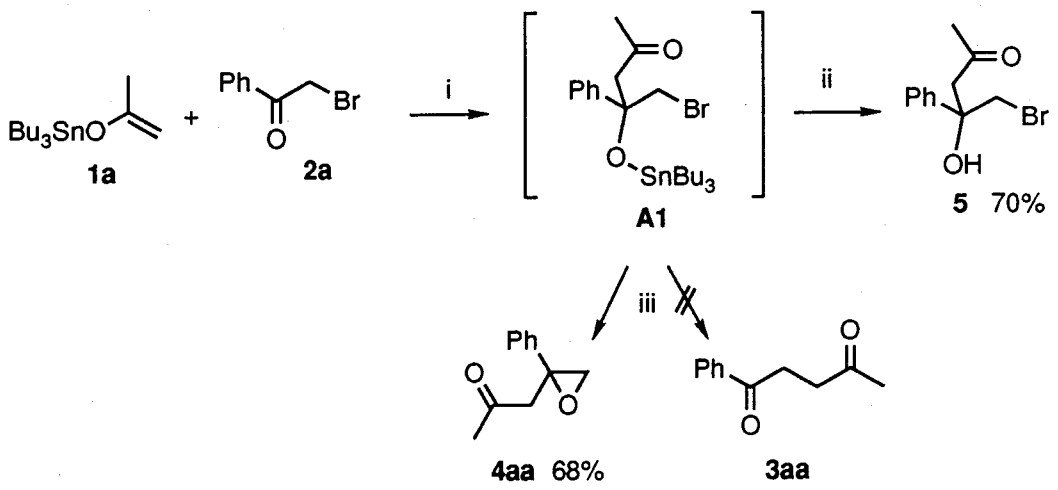
On the mechanism of this reaction, we previously reported that the formation of 1,4-diketones **3** proceeded *via* an ionic mechanism in the presence of HMPA.[8] Two reaction paths can be postulated as shown in Scheme 2. One is the addition of tin enolates to the

carbonyl moiety, giving intermediate **A**, followed by migration of oxoalkyl group. A similar migration-mechanism has been proposed in the reaction of Grignard reagents with α-halo ketones.[10] The other is a direct nucleophilic substitution at the halide moiety. The plausibility of the latter path has been proved as follows.



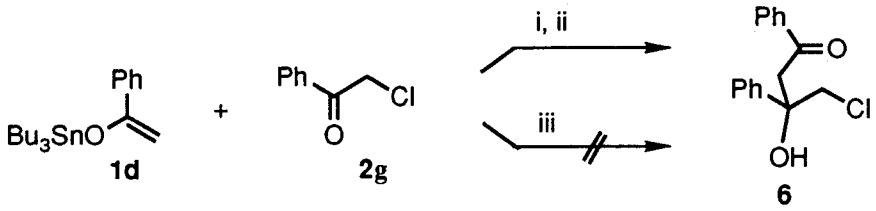
Scheme 2

The intermediate **A1** was formed from 2-bromoacetophenone **2a** and acetonyltributyltin **1a**, as confirmed by hydrolysis to the corresponding bromohydrin derivative **5** (70% yield) (Scheme 3). However no 1,4-diketone was obtained by the addition of HMPA to the solution of **A1** under conditions similar to Table 1, only oxirane **4aa** being obtained in 68% yield.



Scheme 3 *Reagents and conditions:* i, room temp., 2 h; ii, H_2O; iii, HMPA, room temp., 1 h.

Using 2-chloroacetophenone **2g** in the place of the bromide, there was no reaction in the presence of 1.5 molar equivalents of HMPA (Scheme 4), whereas in its absence a chlorohydrin derivative **6** was produced in excellent yield at 40 °C after 8 h. Here we can conclude that the formation of 1,4-diketones is due to the direct substitution at the halide moiety.

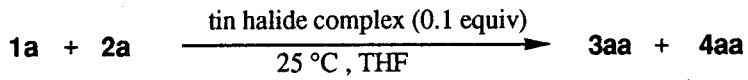


Scheme 4 *Reagents and conditions:* i, Benzene 40 °C, 8 h; ii, H_2O, 95%; iii, HMPA, benzene, 40 °C, 8 h, no reaction.

1-4 Tin Halide Complex-Catalyzed Reaction

However, the question of why oxirane formation was promoted, besides 1,4-diketone formation, by the addition of Lewis bases was still open. Tributyltin bromide is produced as a by-product whether 1,4-diketones or oxiranes are formed. It is well known to form a stable complex with HMPA or ammonium halides.[11] The addition of tributyltin bromide with HMPA was found to promote the formation of oxirane **4aa** at ambient temperature as shown in Table 2, and 0.1 equivalent of the complex was sufficient to give **4aa** in a high yield.

Table 2 Tin halide complex-catalyzed preparation of oxirane



Tin halide complex	Time (h)	Yield (%) [a]	
		3aa	**4aa**
Bu_3SnBr-Bu_4NBr	2	14	66
Bu_3SnBr-HMPT	21	15	65

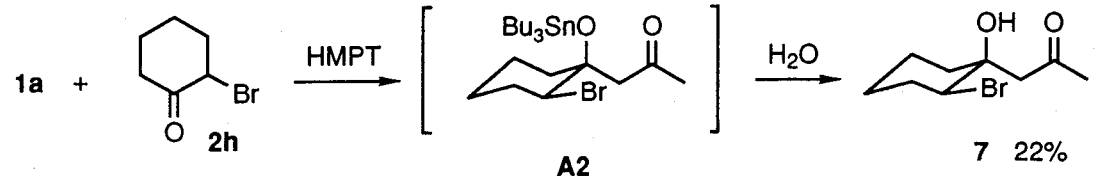
[a] GLC yield.

This is perhaps the reason why the formation of oxirane is accelerated by the additives such as HMPA and Bu_4NBr, and why more than an equimolar amount of these additives is required for the predominant formation of 1,4-diketones.

1-5 Reaction with α-Bromo Cycloalkanone or α-Bromo Aldehyde

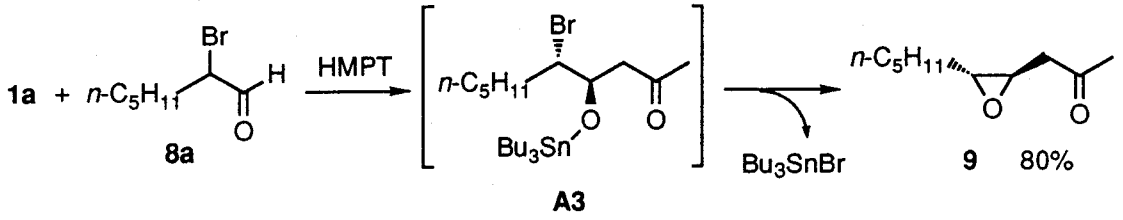
Unfortunately no 1,4-diketone was obtained in the reaction with 2-bromocyclohexanone **2h**. In this reaction only the addition to carbonyl carbon took place, giving a low yield of bromohydrin derivative **7** as a single isomer (Scheme 5). The oxirane was not formed at all because tin alkoxide **A2** has the stannoxy group and bromine atom *cis*.

Scheme 5



The coupling reaction to α-bromo aldehyde **8a**, even in the presence of 1.5 equivalent of HMPA, gave only an oxirane **9** in 80% yield (Scheme 6). In this case HMPA was thought to effect the elimination of tributyltin bromide since only a 10% yield was obtained without it.

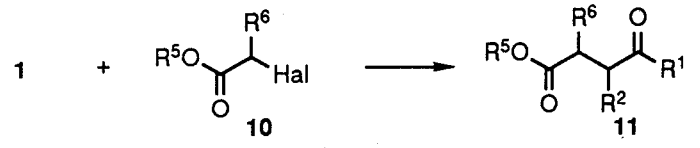
Scheme 6



1-6 Reaction of Tin Enolate with α-Halo Ester

The protocol of adding Lewis bases could be also applied to α-halo esters. Table 3 summarizes the formation of γ-keto esters **11** from α-halo esters **10** and tin enolates **1**. No reaction of **1a** with **10a** proceeded under irradiation with UV. This reaction has been reported to give the corresponding γ-keto ester **11aa** in only 41% yield under Pd-catalysed conditions at 100 °C for 9 h.[5] In contrast, the addition of HMPA gave **11aa** in 90% yield at ambient temperature (Entry 1). A radical inhibiter, 2,2,6,6-tetramethylpiperidin-1-yloxy, did not affect the yield. A cyclic substrate, α-bromo-γ-butyrolactone **10c** was inert toward this nucleophilic substitution assisted by HMPA, but the cross coupling product was obtained using Bu_4NBr though in low yield (10%). The ammonium bromide also effected the reaction of the secondary α-bromo ester **10b** to afford a good yield of the corresponding γ-keto ester **11ab** at ambient temperature, whereas HMPA required a higher temperature. α-Chloro ester **10d** gave **11aa** in a good yield by addition of 0.1 equivalent of tributyltin iodide by which the chloro ester **10d** would be converted into the reactive iodo ester (Entry 5). Unfortunately, this method could not be applied to α-chloroacetophenone.

Table 3 Reaction of tin enolate **1** with α-halogeno esters **10**



	R^5	R^6	Hal
10a;	Et	H	Br
b;	Et	Me	Br
c;	$-(CH_2)_2-$		Br
d;	Et	H	Cl

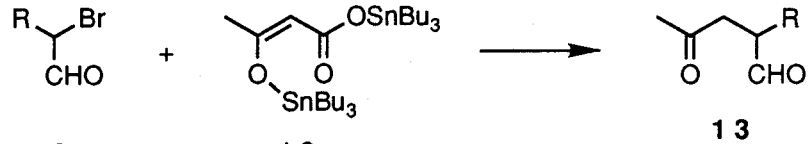
Entry	Enolate	Halo ester	Additive	T/°C	Time/h	Product (yield %)[a]
1	**1a**	**10a**	HMPA	25	7	**11aa** (90)
2	**1a**	**10b**	HMPA	80	7	**11ab** (55)
3	**1a**	**10b**	Bu_4NBr	25	8	**11ab** (80)
4	**1a**	**10c**	Bu_4NBr	25	2	**11ac** (10)
5[b]	**1a**	**10d**	HMPA	25	24	**11aa** (75)
6	**1b**	**10a**	HMPA	25	1	**11ba** (64)
7	**1c**	**10a**	HMPA	25	4	**11ca** (95)
8	**1d**	**10a**	HMPA	25	4	**11da** (69)

[a] GLC yield. [b] Bu_3SnI (0.1 equiv) was added.

1-7 Reaction of Tin Enolate Derived from the Ring Opening of Diketene by Bis(tributyltin) Oxide

One disturbing problem remains: the halide-selective coupling can not be accomplished with α-halo aldehydes. For example, the reaction of 2-bromoheptanal (**8a**) with tributyltin enolate **1a** gave a β-ketooxirane even in the presence of HMPA; exclusive carbonyl addition was followed by the elimination of Bu_3SnBr (Scheme 6).

In contrast, as demonstrated in our recent report, novel tin enolate **12**, generated by the ring opening of diketene with bis(tributyltin) oxide [$(Bu_3Sn)_2O$],[19] induced effective Michael addition,[20] which rarely occurs with conventional organotin enolates. This unique reactivity can be ascribed to the intramolecular coordination of the carbostannyloxy group to the enolate tin center. We have now found that enolate **12** participates in a valuable chemoselective cross coupling at the bromide moiety of α-bromo aldehydes (Scheme 7).



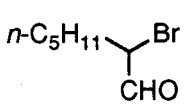
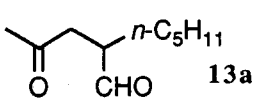
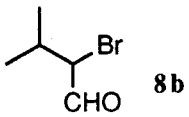
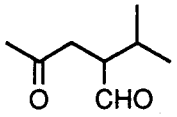
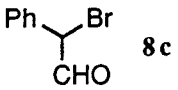
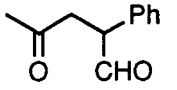
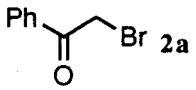
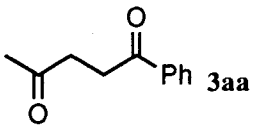
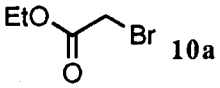
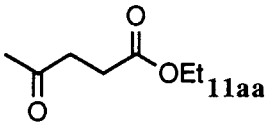
8 **12** **13**

Scheme 7

Table 4 summarizes the coupling reactions of **12**, which was easily prepared *in situ* at 0 °C for 10 min. First, we examined the reaction of **12** with 2-bromoheptanal (**8a**) at 40 °C for 24 h. During the reaction, decarboxylation was observed, and keto aldehyde **13a** was obtained in 40% yield (entry 1). It is noteworthy that the reaction proceeded only at the bromide moiety, and no products derived from addition to the carbonyl moiety were produced. This dramatic change in chemoselectivity indicates that the intramolecular coordination in **12** changes the nucleophilicity of the tin enolate more effectively than does the intermolecular coordination of HMPA to tin enolate **1a**.[6] Moreover, the use of LiBr as an additive accelerated the reaction, and keto aldehyde **13a** could be obtained in 74 % yield at rt for 2 h (entry 2). Similarly, a bromoaldehyde bearing a branched

substituent, **8b**, and an aromatic substrate, **8c**, also gave the corresponding keto aldehydes, **13b** and **13c**, respectively (entries 3 and 4). In all entries examined, no adducts derived from carbonyl addition were obtained. As expected, α-bromoketone **1d** and α-bromoester **1e** undergo chemoselective reaction at the bromide moiety to furnish 1,4-diketones, **4d** and **4e**, respectiely, in good yields (entries 5 and 6). Obviously, enolate **12** is a synthon of enolate **1a**.

Table 4. Preparation of Methyl Ketone Derivatives[a]

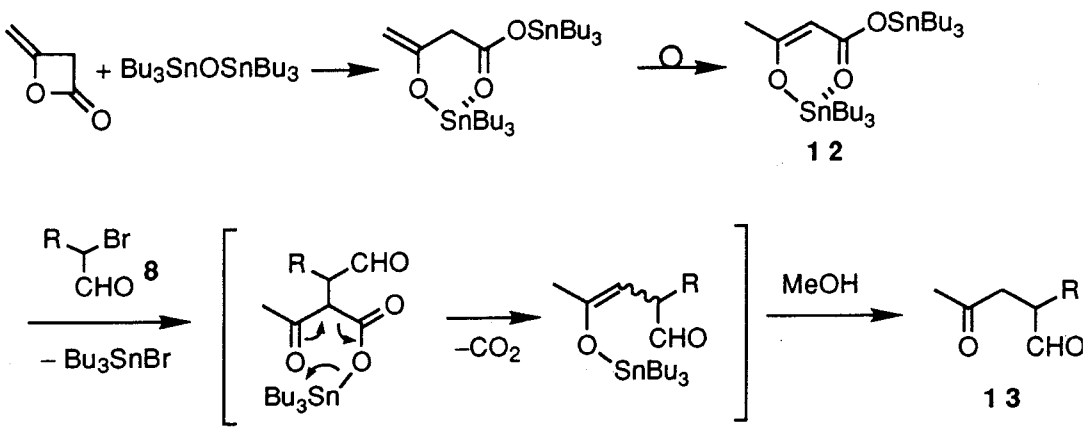
etnry	bromo carbonyls	condns	product	yield[b] (%)
1	 **8a**	40 °C, 24 h	 **13a**	40[c]
2		rt, 24 h		74
3	 **8b**	rt, 24 h	 **13b**	77
4	 **8c**	rt, 24 h	 **13c**	44
5	 **2a**	rt, 24 h	 **3aa**	80
6	 **10a**	rt, 8 h	 **11aa**	85

[a] Enolate **12** was prepared in situ by the reaction of diketene (2 mmol) and $(Bu_3Sn)_2O$ (2 mmol) at 0 °C for 10 min. Alkylation step: bromo carbonyl, 2 mmol, LiBr, 2 mmol, THF, 2 mL. [b] Isolated yield. [c] Without LiBr.

The reaction path is detailed in Scheme 8. Initially, regioselective ring opening of diketene takes place at the acyl-oxygen bond to afford an *exo*-methylene-type tin enolate, which isomerizes to stable enolate **12**. Next, enolate **12** exclusively attacks the bromide

moiety of **8**, and this attack is accompanied by smooth decarboxylation.[21] Finally, keto aldehyde **13** is formed when the reaction mixture is quenched with MeOH.

Scheme 8



In summary, chemoselective carbon-carbon bond formation was performed with tin enolate **12** derived from diketene. The presented method enlarges not only organotin chemistry but also the utility of diketene.

1-8 Experimental Section

Melting points were taken on a Yanagimoto melting point apparatus and are uncorrected. IR spectra were recorded on a Hitachi 260-30 spectrophotometer. ^{1}H NMR spectra were obtained with a Hitachi R-90H (90 MHz) or a JEOL JNM-GSX-400 (400 MHz) spectrometer in $CDCl_3$ solution, with Me_4Si as internal standard. ^{13}C NMR spectra were recorded on a Hitachi R-90H (22.6 MHz) in $CDCl_3$ solution. *J* values are given in Hz. Mass spectra were recorded on a JEOL JMS-DS303 or a Shimadzu GCMS-QP2000A spectrometer. GLC analyses were performed on a Shimadzu GC-8A with FID using a 2 m X 3 mm column packed with SE-52 or FFAP. Flash chromatography was performed on silica gel (Wakogel C-200 or C-300). Bulb-to-bulb distillation was accomplished in a Sibata GTO-250RS at the oven temperature and pressure indicated. Preparative thin layer chromatography was performed using Wakogel B-5F. All

compounds were isolated and identified. Yields were determined by GLC or ^{1}H NMR spectroscopy using internal standards. Tetrahydrofuran (THF) and benzene were distilled from sodium and benzophenone. HMPA was distilled from calcium hydride.

Starting Materials. α-Halo ketones **2a-g** and α-halo esters **10a-d** were commercial products. Bis(tTri-*n*-butyltin) oxide [$(Bu_3Sn)_2O$] and diketene were commercially available. 2-Bromocyclohexanone **2h**[12] and α-Bromo aldehydes **8a-8c**[13] were prepared according to described methods. Tin enolates **1a-d** were prepared by known methods.[14]

General Procedure for Synthesis of 1,4-diketones 3. A mixture of a tin enolate **1** (3.6 mmol) and an additive (5.4 mmol) in dry benzene (3 cm^3) was stirred for 10 min under nitrogen. To this solution was added a α-bromo ketone **2** (3.0 mmol), and stirring under the reaction conditions noted in Table 1. Volatiles were removed under reduced pressure, diethyl ether (100 cm^3) and aqueous NH_4F (15%; 40 cm^3) were added and the resulting Bu_3SnF was filtered off. The filtrate was washed with water (50 cm^3 X 2), dried ($MgSO_4$) and evaporated. Flash chromatography of the resultant residue on silica gel gave 1,4-diketone **3** and β-keto oxirane **4**.

1-Phenyl-1,4-pentanedione (3aa).[4] Obtained from **1a** and **2a** according to the general procedure by flash chromatography (eluted by hexane-benzene, 1:1) and distillation, b.p. 137 °C/1 mmHg; ν_{max}/cm^{-1} 1720 and 1690 (C=O); δ_H(90 MHz) 2.26 (3 H, s, 5-H_3), 2.89 (2 H, t, *J* 6.3, 3-H_2), 3.28 (2 H, t, *J* 6.3, 2-H_2), 7.3-7.65 (3 H, m, ArH) and 7.85-8.1 (2 H, m, ArH); δ_C(22.6 MHz) 29.7 (q), 32.2 (t), 36.8 (t), 127.6 (d), 128.2 (d), 132.7 (d), 136.3 (s), 198.0 (s) and 206.6 (s).

1-Phenyl-2-methyl-1,4-pentanedione (3ab).[4] Obtained from **1a** and **2b** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 10:1) and distillation, b.p. 150 °C/1 mmHg; ν_{max}/cm^{-1} 1710 and 1680 (C=O); δ_H(400 MHz) 1.19 (3 H, d, *J* 6.8, 2-Me), 2.18 (3 H, s, 5-H_3), 2.55 (1 H, dd, *J* 18.1 and 4.9, 3-H^a), 3.17 (1 H, dd, *J* 18.1 and 8.3, 3-H^b), 3.97 (1 H, m, 2-H), 7.47 (2 H, m, ArH), 7.56 (1 H, m, ArH) and 7.97 (2 H, m, ArH); δ_C(22.6 MHz) 17.5 (q), 30.0

(q), 36.0 (d), 46.6 (t), 128.1 (d), 128.3 (d), 132.6 (d), 135.7 (s), 202.7 (s) and 206.5 (s); *m/z* 190 (M+, 3%); (Found: M+, 190.0994. $C_{12}H_{14}O_2$ requires *M*, 190.0994).

2,5-Heptanedione (3ac).[15] Obtained from **1a** and **2c** according to the general procedure by distillation without flash chromatography, b.p. 45 °C/18 mmHg, ν_{max}/cm^{-1} 1720 and 1710 (C=O); δ_H(90 MHz) 1.06 (3 H, t, *J* 7.5, 7-H_3), 2.20 (3 H, s, 1-H_3), 2.47 (2 H, q, *J* 7.5, 6-H_2) and 2.70 (4 H, s, 3 and 4-H_2); δ_C(22.6 MHz) 7.7, 29.8, 35.5, 35.8, 36.8, 207.1 and 209.8; *m/z* 128 (M+, 1.6%).

1-(*p*-Methoxyphenyl)-1,4-pentanedione (3ad). Obtained from **1a** and **2d** according to the general procedure by flash chromatography (eluted by benzene), m.p. 49-51 °C (Found: C, 69.71; H, 6.84. $C_{12}H_{14}O_3$ requires C, 69.89; H, 6.84%); ν_{max}/cm^{-1} 1700 and 1665 (C=O); δ_H(400 MHz) 2.25 (3 H, s, 5-H_3), 2.86 (2 H, t, *J* 6.3, 3-H_2), 3.23 (2 H, t, *J* 6.3, 2-H_2), 3.86 (3 H, s, MeO), 6.93 (2 H, d, *J* 8.9, ArH) and 7.96 (2 H, d, *J* 8.9, ArH); δ_C(22.6 MHz) 30.0 (q), 32.0 (t), 37.0 (t), 55.4 (q), 113.6 (d), 129.6 (s), 130.2 (d), 163.4 (s), 196.9 (s) and 207.5 (s); *m/z* 206 (M+, 17%).

1-(*p*-Chlorophenyl)-1,4-pentanedione (3ae). Obtained from **1a** and **2e** according to the general procedure by flash chromatography (eluted by hexane-benzene, 1:1), m.p. 74.5-76 °C (Found: C, 62.49; H, 5.13; Cl, 16.84. $C_{11}H_{11}ClO_2$ requires C, 62.72; H, 5.26; Cl, 16.83%); ν_{max}/cm^{-1} 1710 and 1670 (C=O); δ_H(90 MHz) 2.14 (3 H, s, 5-H_3), 2.76 (2 H, t, *J* 5.8, 3-H_2), 3.13 (2 H, t, *J* 5.8, 2-H_2), 7.32 (2 H, d, *J* 8.3, ArH) and 7.79 (2 H, d, *J* 8.3, ArH); δ_C(22.6 MHz) 30.0 (q), 32.3 (t), 37.0 (t), 128.8 (d), 129.3 (d), 134.9 (s), 139.5 (s), 197.1 (s) and 206.8 (s); *m/z* 212 (M+ + 2, 5%) and 210 (M+, 15).

6,6-Dimethyl-2,5-heptanedione (3af). Obtained from **1a** and **2f** according to the general procedure by flash chromatography (eluted by chloroform) and distillation, b.p. 36 °C/2 mmHg (Found: C, 68.94; H, 10.36. $C_9H_{16}O_2$ requires C, 69.19; H, 10.32%); ν_{max}/cm^{-1} 1695 (C=O); δ_H(90 MHz) 1.18 (9 H, s, Me_3C), 2.21 (3 H, s, 1-H_3) and 2.60-2.88 (4 H, m, 3 and 4-H_2); δ_C(22.6 MHz) 26.0 (q), 29.3 (q), 30.0 (t), 36.3 (t), 43.2 (s), 206.1 (s) and 213.2 (s); *m/z* 157 (M+, 0.3%).

2-(1-Methyl-2-oxopropyl)-2-phenyloxirane (4ba) and 1-phenyl-3-methyl-1,4-pentanedione (3ba). The oxirane **4ba** was prepared by general procedure from **1b** and **2a**. It was isolated as a mixture of stereo isomers **4ba-1** and **4ba-2** by flash chromatography (eluted by hexane-benzene, 2:1) and distillation. The mixture showed b.p. 120 °C/4 mmHg (Found: M+, 190.0975. $C_{12}H_{14}O_2$ requires *M*, 190.0994); ν_{max}/cm^{-1} 1708 (C=O); δ_C(22.6 MHz) 12.2 and 12.4 (q) , 29.6 (q), 51.1 and 52.4 (d), 53.0 (t), 60.1 and 60.7 (s), 126.1, 126.4, 127.7, 128.0, 128.1 (d), 138.1 and 138.5 (s) , 207.7 and 208.4 (s); *m/z* 190 (M+, 0.4%). **4ba-1**; δ_H(400 MHz) 1.17 (3 H, d, *J* 6.9, *Me*CH), 2.18 (3 H, s, *Me*C=O), 2.80 (1 H, d, *J* 4.9, 3-H^a), 3.10 (1 H, d, *J* 4.9, 3-H^b), 3.16 (1 H, q, *J* 6.9, CH) and 7.3 (5 H, m, Ph); and **4ba-2**; δ_H(400 MHz) 1.21 (3 H, d, *J* 7.2, *Me*CH), 2.19 (3 H, s, *Me*C=O), 2.89 (1 H, d, *J* 4.9, 3-H^a), 2.98 (1 H, q, *J* 7.2, CH), 3.04 (1 H, d, *J* 4.9, 3-H^b), and 7.3 (5 H, m, Ph). Continued elution (hexane-benzene, 1:2) gave 1-*phenyl*-3-*methyl*-1,4-*pentanedione* **3ba** and further purification by TLC (R_f 0.24, hexane-diethyl ether, 1:1), b.p. 130 °C/3 mmHg; ν_{max}/cm^{-1} 1715 and 1685 (C=O); δ_H(400 MHz) 1.13 (3 H, d, *J* 7.3, 3-Me), 2.23 (3 H, s, 5-H_3), 2.86 (1 H, dd, *J* 18.1 and 4.4, 2-H^a), 3.14-3.20 (1 H, m, 3-H), 3.46 (1 H, dd, *J* 18.1 and 8.8, 2-H^b), 7.38 (2 H, t, *J* 7.6, ArH), 7.48 (1 H, t, *J* 7.6, ArH) and 7.87 (2 H, m, ArH); δ_C(22.6 MHz) 16.5 (q), 28.4 (q), 41.6 (d), 41.6 (t), 127.7 (d), 128.2 (d), 132.8 (d), 136.4 (s), 198.0 (s) and 210.7 (s); *m/z* 190 (M+, 11%); (Found: M+, 190.0988. $C_{12}H_{14}O_2$ requires *M*, 190.0994).

2-Phenacylcyclohexanone (3ca). Obtained from **1c** and **2a** according to the general procedure (eluted by benzene, 1:1) and distillation, b.p. 120 °C/0.1 mmHg (Found: C, 77.77; H, 7.48. $C_{14}H_{16}O_2$ requires C, 77.75; H, 7.46%); ν_{max}/cm^{-1} 1705 and 1680 (C=O); δ_H(400 MHz) 1.40-1.55 (1 H, m), 1.60-1.95 (3 H, m), 2.10-2.25 (2 H, m), 2.44 (2 H, m), 2.69 (1 H, dd, *J* 17.7 and 5.4, C*H*^{a}H^{b}COPh), 3.16 (1 H, m, 2-H), 3.60 (1 H, dd, *J* 17.7 and 6.6, CH^a*H*^{b}COPh), 7.45 (2 H, m, ArH), 7.55 (1 H, m, ArH) and 8.00 (2 H, m, ArH); δ_C(22.6 MHz) 25.3, 27.9, 34.3, 38.3, 41.9, 46.4, 127.9, 128.4, 132.8, 137.0, 198.4 and 211.2; *m/z* 216 (M+, 6.5%).

1,4-Diphenyl-1,4-butanedione (3da).[16] Obtained from **1d** and **2a** according to the general procedure by recrystallization from hexane-benzene, m.p. 151 °C (Found: C, 80.51; H, 5.80. $C_{16}H_{14}O_2$ requires C, 80.65; H, 5.92%); ν_{max}/cm^{-1} 1672 (C=O); δ_H(90 MHz) 3.46 (4 H, s, 2 and 3-H_2), 7.3-7.6 (6 H, m, ArH) and 7.9-8.1 (4 H, m, ArH); δ_C(22.6 MHz) 32.5 (t), 127.9 (d), 128.4 (d), 132.9 (d), 136.7 (s) and 198.3 (s); *m/z* 238 (M^+, 22%).

Following oxiranes **4** were prepared without additive.

2-Acetonyl-2-phenyloxirane (4aa).[3] A mixture of **1a** (1.25 g, 3.6 mmol) and **2a** (0.60 g, 3.0 mmol) in dry benzene (3 cm^3) was stirred for 3 h at 80 °C under nitrogen, volatiles were removed under reduced pressure, diethyl ether (100 cm^3) and aqueous NH_4F (15%; 40 cm^3) were added and washed with water (50 cm^3 X 2), dried ($MgSO_4$) and evaporated. The residue was flash chromatographed (eluted by benzene-hexane, 1:3) to give oxirane **4aa** which was then purified by distillation, b.p. 100 °C/5 mmHg; ν_{max}/cm^{-1} 1665 (C=O); δ_H(90 MHz) 2.15 (3 H, s, Me), 2.87 (1 H, d, *J* 5.3, 3-H^a), 2.93 (1 H, d, *J* 16.2, C*H*^{a}H^{b}C=O), 3.05 (1 H, d, *J* 5.3, 3-H^b), 3.24 (1 H, d, *J* 16.2, CH^a*H*^{b}C=O) and 7.33 (5 H, s, Ph); δ_C(22.6 MHz) 30.3, 49.5, 55.5, 56.2, 125.2, 127.4, 128.1, 138.9 and 204.8.

(*Z*)- and (*E*)-2-Acetonyl-3-methyl -2-phenyloxirane (4ab). The reaction of **1a** (1.25 g, 3.6 mmol) and **2b** (0.64 g, 3.0 mmol) in dry benzene (3 cm^3) for 24 h at 80 °C gave the mixture of (*Z*)- and (*E*)-**4ab** under nitrogen, and work-up was performed similarly as above. The residue was flash chromatographed and oxirane (*E*)-**4ab** (eluted by hexane-diethyl ether, 10:1) was isolated. (Found: C, 75.53; H, 7.21. $C_{12}H_{14}O_2$ requires C, 75.76; H, 7.42%); ν_{max}/cm^{-1} 1712 (C=O); δ_H(400 MHz) 1.42 (3 H, d, *J* 5.5, 3-Me), 2.13 (3 H, s, *Me*C=O), 3.00 (1 H, d, *J* 17.0, C*H*^{a}H^b), 3.05 (1 H, q, *J* 5.5, 3-H), 3.18 (1 H, d, *J* 17.0, CH^a*H*^{b}) and 7.32 (5 H, m, Ph); δ_C(22.6 MHz) 14.8 (q), 30.3 (q), 47.1 (t), 60.4 (s), 62.2 (d), 125.4(d), 127.5 (d), 128.4 (d), 140.6 (s) and 205.3 (s); *m/z* 190 (M^+, 2.2%), 105 (11), 103 (30), 77 (15) and 43 (100); (Found: M^+, 190.0982. $C_{12}H_{14}O_2$ requires *M*, 190.0994). When the methyl signal at δ 1.42 (2-

H) was irradiated, NOEs with the methylene protons (δ 3.00, d) and (δ 3.18, d) were observed. Continued elution gave (*Z*)-**4ab**[3]; ν_{max}/cm^{-1} 1700 (C=O); δ_H(400 MHz) 1.02 (3 H, d, *J* 5.4, 3-Me), 2.11 (3 H, s, *Me*CO), 2.87, 3.16 (each 1 H, each d, each *J* 15.8, CH_2), 3.23 (1 H, q, *J* 5.4, 3-H) and 7.34 (5 H, m, Ph); δ_C(22.6 MHz) 13.8 (q), 30.5 (q), 51.8 (t), 59.8 (q), 61.6 (s), 126.5 (d), 127.2 (d), 127.8 (d), 137.1 (s) and 204.9 (s); *m/z* 190 (M$^+$, 0.6%), 189 (1.5), 103 (68.5), 77 (34.9), 43 (100). Irradiation of the methyl signal at δ 1.02 caused no NOE on the signals of methylene protons.

2-Acetonyl-2-ethyloxirane (4ad). This compound was prepared by the reaction of **1a** (3.47 g, 10 mmol) and **2d** (0.76 g, 5.0 mmol) for 5 h at room temperature without solvent and distilled at 80 °C (2 mmHg) to give the *title compound* (56% yield), which was further purified by distillation, b.p. 120 °C/30 mmHg; ν_{max}/cm^{-1} 1715 (C=O); δ_H(400 MHz) 0.92 (3 H, t, *J* 7.5, *Me*CH_2), 1.68, 1.69 (2 H, 2 X q, *J* 7.3, 7.5 Me*C*H_2), 2.20 (3 H, s, MeC=O), 2.58, (1 H, d, *J* 15.6, C*H*^{a}H^{b}C=O), 2.64, 2.73 (each 1 H, each d, each *J* 4.9, 3-H_2) and 2.80 (1 H, d, *J* 15.6, CH^a*H*^{b}C=O); δ_C(22.6 MHz) 8.4 (q), 27.2 (t), 30.6 (q), 48.4 (t, $^1J_{C,H}$ 127.1, *C*H_2C=O), 51.6 (t, $^1J_{C,H}$ 173.4, C-3), 56.9 (s) and 205.4 (s); *m/z* 128 (M$^+$, 0.1%), 55 (32.7) and 43 (100); (Found: M$^+$, 128.0828. $C_{12}H_{14}O_2$ requires *M*, 128.0838).

2-Acetonyl-2-(*p*-chlorophenyl)oxirane (4ae). A mixture of **1a** (1.25 g, 3.6 mmol) and **2e** (0.64 g, 3.0 mmol) in dry benzene (3 cm^3) was stirred for 15 h at 80 °C and work-up was performed similarly as isolated of **4aa**. The residue was flash chromatographed and oxirane **4ae** (eluted by hexane-diethyl ether, 3:1) was isolated, (Found: C, 62.49; H, 5.23; Cl, 16.83. $C_{11}H_{11}ClO_2$ requires C, 62.72; H, 5.26; Cl, 16.83%); ν_{max}/cm^{-1} 1710 (C=O); δ_H(400 MHz) 2.16 (3 H, s, Me), 2.84, (1 H, d, *J* 4.6, 3-H^a), 2.95 (1 H, d, *J* 16.4, C*H*^{a}H^{b}C=O), 3.04 (1 H, d, *J* 4.6, 3-H^b), 3.19 (1 H, d, *J* 16.4, CH^a*H*^{b}C=O) and 7.2-7.35 (4 H, m, ArH); δ_C(22.6 MHz) 30.6 (q), 49.8 (t), 55.7 (t), 56.2 (s), 126.9 (d), 128.5 (d), 133.7 (s), 137.6 (s) and 204.8 (s); *m/z* 210 (M$^+$, 0.8%), 182 (6.6) and 43 (100); (Found: M$^+$, 210.0434. $C_{11}H_{11}ClO_2$ requires *M*, 210.0448).

Formation of 1,4-diketone (3aa) under UV irradiation. A mixture of **1a** (1.25 g, 3.6 mmol) and **2a** (0.60 g, 3.0 mmol) was irradiated in freshly distilled benzene with a 250-W high pressure mercury lamp, and stirred for 2 h at ambient temperature under nitrogen.

5-Bromo-4-hydroxy-4-phenyl-2-pentanone (5). A mixture of acetonyltributyltin **1a** (1.74 g, 5.0 mmol) and 2-bromoacetophenone **2a** (0.20g, 1.0 mmol) was stirred at room temperature under nitrogen for 2 h. This reaction mixture was added to diethyl ether (100 cm^3) and aqueous NH_4F (15%; 40 cm^3) stirring for 1 h and washed with water (50 cm^3 X 2), dried ($MgSO_4$) and evaporated. The residue was flash chromatographed and bromohydrin **7** (eluted by hexane-diethyl ether, 4:1) was isolated, ν_{max}/cm^{-1} 3450 (OH), 1700 (C=O); δ_H(400 MHz) 2.13 (3 H, s, 1-H_3), 3.26 (2 H, s, 3-H_2), 3.59, 3.62 (each 1 H, each d, each *J* 10.7, 5-H_2), 4.64 (1 H, br s, OH) and 7.25-7.47 (5 H, m, Ph); δ_C(22.6 MHz) 31.8 (q, C-1), 42.8 (t, $^1J_{C,H}$ 153.4, C-5), 50.2 (t, $^1J_{C,H}$ 126.4, C-3), 74.4 (s, C-4), 124.9 (d), 127.7 (d), 128.4 (d), 142.7 (s) and 209.4 (s, C-2); *m/z* (CI) 259 (M^+ + 3, 22%) and 257 (M^+ + 1, 24); [Found: $(M + H)^+$, 257.0159. $C_{11}H_{14}BrO_2$ requires *M*, 257.0177].

4-Chloro-3-hydroxy-1,3-diphenyl-1-pentanone (6).—A mixture of phenacyltributyltin **1d** (1.64 g, 4.0 mmol) and 2-chloroacetophenone **2g** (0.31 g, 2.0 mmol) in dry benzene (2 cm^3) was stirred at 40 °C under nitrogen for 8 h. This reaction mixture was added to diethyl ether (100 cm^3) and aqueous NH_4F (15%; 40 cm^3) stirring for 1 h and washed with water (50 cm^3 X 2), dried ($MgSO_4$) and evaporated. The residue was flash chromatographed (eluted by hexane-diethyl ether, 5:1) to give chlorohydrin **6** which was then purified by TLC (R_f 0.26, hexane-diethyl ether, 5:1) (Found: C, 69.87; H, 5.51; Cl, 12.92. $C_{16}H_{15}ClO_2$ requires C, 69.95; H, 5.50; Cl, 12.90%); ν_{max}/cm^{-1} 3450 (OH) and 1662 (C=O); δ_H(400 MHz) 3.69, 3.91 (each 1 H, each d, each *J* 17.3, 2 or 4-H_2), 3.74, 3.82 (each 1 H, each d, each *J* 11.5, 2 or 4-H_2), 5.01 (1 H, s, OH) and 7.2-8.0 (10 H, m, 2 X Ph); δ_C(22.6 MHz) 43.8 (t), 52.9 (t), 75.2 (s), 124.8 (d), 127.2 (d), 127.7 (d), 128.0 (d), 128.3 (d), 133.4 (d), 136.3 (s), 142.9 (s) and 200.2 (s); *m/z*

277 (M^+ + 3, 0.15%) and 275 (M^+ + 1, 0.47). In the presence of HMPA (1.07 g, 6 mmol) the reaction of phenacyltributyltin **1d** (1.64 g, 4.0 mmol) and 2-chloroacetophenone **2g** (0.31 g, 2.0 mmol) in dry benzene (2 cm^3) did not proceed at all.

Formation of oxirane (4aa) catalyzed by tributyltin bromide complexes. A mixture of tributyltin bromide (37 mg, 0.1 mmol) and tetrabutylammonium bromide (32 mg, 0.1 mmol) in THF (1 cm^3) was stirred for 20 min and acetonyltributyltin **1a** and 2-bromoacetophenone **2a** were added, then stirred for 2 h under nitrogen.

1-Acetonyl-*c*-2-bromocyclohexan-*r*-1-ol (7). A mixture of **1a** (2.08 g, 6.0 mmol) and HMPA (1.61 g, 9.0 mmol) in dry benzene (5 cm^3) was stirred for 10 min under nitrogen. To this solution was slowly added 2-bromocyclohexanone **2h** (0.89 g. 5.0 mmol). After the mixture had been stirred for 7 h at ambient temperature, volatiles were removed under reduced pressure, diethyl ether (100 cm^3) and aqueous NH_4F (15%; 40 cm^3) were added and washed with water (50 cm^3 X 2), dried ($MgSO_4$) and evaporated. The residue was flash chromatographed (eluted by hexane-diethyl ether, 1:1) to give bromohydrin **7** which was then purified by distillation, b.p. 80 °C/0.3 mmHg; ν_{max}/cm^{-1} 3420 (OH), 1705 (C=O); δ_H(400 MHz) 1.2-2.35 (8 H, m, ring methylene protons) 2.20 (3 H, s, Me), 2.68, 2.96 (each 1 H, each d, each *J* 16.8, CH_2C=O), 3.20 (1 H, br s, OH) and 4.30 (1 H, dd, *J* 11.7, 4.6, 2-H); δ_C(22.6 MHz) 20.6 (t), 26.8 (t), 32.0 (q, Me), 33.4 (t), 36.0 (t), 53.4 (t, CH_2C=O), 63.5 (d, C-2), 72.2 (s, C-1) and 208.6 (s, C=O). Satisfactory data of high resolution mass spectrum and elemental analysis of the *title compound* **7** could not be obtained due to its instability. Its ^1H and ^{13}C NMR were in good analogy with 1-acetonyl-*c*-2-bromo-*c*-4-*tert*-butylcyclohexan-*r*-1-ol **9'** formed by a similar method as above. Stereo chemistry of compound **7'** which has a fixed conformation was established by ^1H NMR spectroscopy. When the proton at δ 4.31 (2-H) was irradiated, NOEs with the methylene protons (δ 2.65, d) and (δ 2.98, d) were observed. 1-Acetonyl-*c*-2-bromo-*c*-4-*tert*-butylcyclohexan-*r*-1-ol **7'**.—m.p. 54-56 °C (Found: C, 53.47; H, 7.94; Br, 27.31. $C_{13}H_{23}BrO_2$ requires C, 53.62; H, 7.96; Br,

27.44%) ν_{max}/cm^{-1} 3480 (OH) and 1700 (C=O); δ_H(400 MHz) 0.87 (9 H, s, Bu^t) 1.05-2.2 (7 H, m, ring methylene protons) 2.19 (3 H, s, MeC=O), 2.65, 2.98 (each 1 H, each d, each *J* 17.1, C*H*$_2$C=O), 3.18 (1 H, br s, OH) and 4.31 (1 H, dd, *J* 12.2, 4.4, 2-H); δ_C(22.6 MHz) 21.5 (t), 27.5 (q, *Me*$_3$C), 32.0 (q, *Me*C=O), 32.6 (s, *C*Me$_3$) 34.9 (t), 35.8 (t), 49.6 (d, C-4), 53.7 (t, *C*H$_2$C=O), 64.5 (d, C-2), 71.8 (s, C-1) and 208.6 (s, C=O); *m/z* (CI) 293 (M$^+$ + 3, 88%) and 291 (M$^+$ + 1, 90).

***trans*-2-Acetonyl-3-pentyloxirane (9).** A mixture of **1a** (0.83 g, 2.4 mmol) and HMPA (0.64 g, 3.6 mmol) in dry benzene (2 cm^3) was stirred for 10 min under nitrogen. To this solution was slowly added 2-bromoheptanal **8a** (0.39 g. 2 mmol). After the mixture had been stirred for 1 h at ambient temperature, volatiles were removed under reduced pressure, diethyl ether (100 cm^3) and aqueous NH_4F (15%; 40 cm^3) were added and washed with water (50 cm^3 X 2), dried ($MgSO_4$) and evaporated. The residue was flash chromatographed (eluted by benzene-hexane, 4:1) to give oxirane **9** which was then purified by distillation, b.p. 115 °C/4 mmHg; ν_{max}/cm^{-1} 1710 (C=O); δ_H(90 MHz) 0.90 (3 H, t, *J* 5.7, *Me*CH$_2$), 1.1-1.8 (8 H, m, methylene protons), 2.20 (3 H, s, MeC=O), 2.64 (2 H, d, *J* 5.7, CH$_2$C=O), 2.7 (1 H, m, 3-H) and 3.00 (1 H, dt, *J* 2.2 and 5.7, 2-H); δ_C(22.6 MHz) 13.6 (q), 22.2 (t), 25.2 (t), 30.0 (q), 31.3 (t), 31.4 (t), 46.1 (t), 53.4 (d), 58.1 (d) and 205.2 (s); *m/z* 170 (M$^+$, 0.4%); (Found: M$^+$, 170.1267. $C_{10}H_{18}O_2$ requires *M*, 170.1307). The ^{13}C NMR spectroscopic data showed a small amount of *cis*-isomer, some of whose absorbances were paired with those of **11**. This *cis*-isomer could not be isolated.

General Procedure for Synthesis of γ-keto esters (11). These reactions were performed in a similar manner described in general procedure for preparation of 1,4-diketones **3**.

Ethyl 4-oxopentanoate (11aa). Obtained from **1a** and **10a** according to the general procedure by flash chromatography (eluted by hexane-benzene, 1:1) and distillation; b.p. 120 °C/30 mm Hg (Found: C, 58.04; H, 8.45. $C_7H_{12}O_3$ requires C, 58.32; H, 8.39%); ν_{max}/cm^{-1} 1720 (C=O); δ_H(90 MHz) 1.26 (3 H, t, *J* 7.1, *Me*CH$_2$),

2.20 (3 H, s, 5-H_3), 2.5-2.9 (4 H, m, 2 and 3-H_2) and 4.15 (2 H, q, *J* 7.1, MeCH_2); δ_C(22.6 MHz) 14.1 (q), 28.0 (t), 29.8 (q), 37.9 (t), 60.5 (t), 172.5 (s) and 206.3 (s); *m/z* 144 (M^+, 12%).

Ethyl 2-methyl-4-oxopentanoate (11ab).[17] Obtained from **1a** and **10b** according to the general procedure by flash chromatography (eluted by pentane) and distillation, b.p. 120 °C/20 mmHg; ν_{max}/cm^{-1} 1720 (C=O); δ_H(400 MHz) 1.18 (3 H, d, *J* 6.84, 2-Me), 1.25 (3 H, t, *J* 7.1, *Me*CH_2), 2.16 (3 H, s, 5-H_3), 2.46 (1 H, dd, *J* 20.8 and 8.5, 3-H^a), 2.92 (2 H, m, 3-H^b and 2-H) and 4.13 (2 H, q, *J* 7.1, MeCH_2); δ_C(22.6 MHz) 14.1 (q), 17.0, (q) 29.9 (q), 34.7 (d), 46.6 (t), 60.5 (t), 175.5 (s) and 206.4 (s); *m/z* 158 (M^+, 3.4%).

α-Acetonyl-γ-butyrolactone (11ac). Although this compound was not purified, the identity was confirmed in comparison with the reported ^1H NMR spectroscopic data.[5] The yield of **11ac** was determined by the ^1H NMR spectrum of a crude reaction mixture obtained from **1a** and **10c** according to the general procedure. δ_H(400 MHz) 2.21 (3 H, s, Me), 2.66 (1 H, dd, *J* 18.3 and 8.3, C*H*^{a}H^{b}C=O), 2.95 (1 H, m, CH), 3.12 (1 H, dd, *J* 18.3 and 3.4, CH^a*H*^{b}C=O), 4.23 (1 H, ddd, J 10.4, 9.2 and 6.6, OC*H*^{a}H^b), 4.40 (1 H, m, OCH^a*H*^{b}). The other signals (CH_2CH_2O) overlapped with other products like tributyltin halides.

Ethyl 3-methyl-4-oxopentanoate (11ba).[18] Obtained from **1b** and **10a** according to the general procedure by flash chromatography (eluted by benzene) and distillation, b.p. 70 °C/5 mmHg; ν_{max}/cm^{-1} 1710 (C=O); δ_H(400 MHz) 1.16 (3 H, d, *J* 6.8, 3-Me), 1.25 (3 H, t, *J* 7.1, *Me*CH_2), 2.22 (3 H, s, 5-H_3), 2.30 (1 H, dd, *J* 16.9 and 5.6, 2-H^a), 2.76 (1 H, dd, *J* 16.9 and 8.6, 2-H^b), 3.00 (1 H, m, 3-H) and 4.11 (2 H, q, *J* 7.1, MeCH_2); δ_C(22.6 MHz) 14.1 (q), 16.4 (q), 28.2 (q), 36.9 (t), 42.7 (d), 60.3 (t), 171.9 (s) and 210.2 (s); *m/z* 158 (M^+, 7.4%).

Ethyl 2-(2-oxocyclohexyl)acetate (11ca). Obtained from **1c** and **10a** according to the general procedure by flash chromatography (eluted by hexane) and distillation, b.p. 70 °C/5 mmHg (Found: C, 65.19; H, 8.75. $C_{10}H_{16}O_3$ requires C,

64.92; H, 8.92%); ν_{max}/cm^{-1} 1720 and 1708 (C=O); δ_H(400 MHz) 1.26 (3 H, t, *J* 7.1, *Me*CH_2), 1.33-2.2 (6 H, m, ring methylene protons), 2.14 (1 H, dd, *J* 16.4 and 6.1, 2-H^a), 2.3-2.45 (2 H, m, C*H*$_2$COCH), 2.77 (1 H, dd, *J* 16.4 and 7.1, 2-H^b), 2.8-2.95 (1 H, m, CH) and 4.13 (2 H, q, *J* 7.1, MeC*H*$_2$); δ_C(22.6 MHz) 14.2 (q), 25.2 (t), 27.7 (t), 33.8 (t), 34.4 (t), 41.7 (t), 47.0 (d), 60.3 (t), 172.2 (s) and 210.5 (s); *m/z* 184 (M+, 17%).

Ethyl 4-oxo-4-phenylbutanoate (11da).—Obtained from **1d** and **10a** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 10:1) and further purification by TLC (R_f, 0.3, hexane-diethyl ether, 3:1), b.p. 135 °C/0.3 mmHg, (Found: C, 69.78; H, 6.83. $C_{12}H_{14}O_3$ requires C, 69.89; H, 6.84%); ν_{max}/cm^{-1} 1722 and 1683 (C=O); δ_H(400 MHz) 1.27 (3 H, t, *J* 7.1, Me), 2.76 (2 H, t, *J* 6.6, 2-H$_2$), 3.32 (2 H, t, *J* 6.6, 3-H$_2$), 4.16 (2 H, q, *J* 7.1, MeC*H*$_2$), 7.3-7.59 (3 H, m, ArH) and 7.98 (2 H, m, ArH); δ_C(22.6 MHz) 14.0 (q), 28.1 (t), 33.2 (t), 60.3 (t), 127.6 (d), 128.2 (d), 132.8 (d), 136.3 (s), 172.3 (s) and 197.6 (s); *m/z* 206 (M+, 7%).

4-Formylnonan-2-one (13a). General Procedure for the Preparation of Keto Aldehydes. Diketene (0.174 g, 2 mmol) was added to a solution of 1.19g of $(Bu_3Sn)_2O$ (2 mmol) in THF (2 mL), and the mixture was stirred at 0 °C for 10 min. The disappearence of the IR absorption band of diketene at 1900 cm^{-1} indicated that the ring opening of diketene to form enolate **12** had occurred. Then 0.39 g of 2-bromoheptanal (**8a**) (2 mmol), and 0.17g of LiBr (2 mmol) were successively added, and the mixture was stirred at rt for 2 h. After the mixture was quenched with MeOH (5 mmol), the solvent was removed under reduced pressure. The residue was subjected to column chromatography with 1:1 hexane/ ethyl acetate to give 0.25 g of **13a** (74%). Further purification was performed by TLC with 2:1 hexane/ethyl ether.

IR (neat) 1710, 1720 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ0.88 (t, 3H, *J*=7.0 Hz, CH_3), 1.25-1.70 (m, 8H,CH_2), 2.19 (s, 3H, CH_3C=O), 2.45 (dd, 1H, *J*=8.0 and 21.3 Hz one of CH_2Ac), 2.83-2.93 (m, 2H, one of CH_2Ac and C*H*CHO), 9.70 (s, 1H, CHO); ^{13}C

NMR ($CDCl_3$) δ13.78, 22.28, 26.55, 28.51, 29.93, 31.67, 42.13, 46.73, 203.21, 206.37; HRMS m/z calcd for $C_{10}H_{18}O_2$ 170.1307. Found 170.1301.

4-Formyl-5-methylhexan-2-one (13b): IR (neat) 1710, 1720 cm^{-1}; ^1H NMR ($CDCl_3$) δ0.92 (d, 3H, *J*=6.8 Hz, CH_3), 1.01 (d, 3H, *J*=6.8 Hz, CH_3), 2.13-2.23 (m, 1H, $CHMe_2$), 2.21 (s, 3H, CH_3C=O), 2.34 (dd, 1H, *J*=7.3 and 22.0 Hz, one of CH_2), 2.88-2.95 (m, 2H, one of CH_2 and C*H*CHO), 9.75 (s, 1H, CHO); ^{13}C NMR ($CDCl_3$) δ19.26, 20.35, 29.48, 30.90, 38.56, 52.59, 203.69, 206.97; HRMS: m/z calcd for $C_8H_{14}O_2$ 142.0994. Found 142.0990.

4-Formyl-4-phenylbutan-2-one (13c): IR (neat): 1710, 1720 cm^{-1}; ^1H NMR ($CDCl_3$) δ2.19 (s, 3H, CH_3), 2.65 (dd, *J*=4.9 and 18.1 Hz, CHPh), 3.36 (dd, 1H, *J*=8.8 and 18.1 Hz, one of CH_2Ac), 4.22 (dd, 1H, *J*=4.9 and 8.8 Hz, one of CH_2Ac), 7.17-7.38 (m, 5H, Ph), 9.67 (s, 1H, CHO); ^{13}C NMR ($CDCl_3$): δ30.01, 43.59, 53.55, 127.79, 128.83, 129.17, 135.09, 198.79, 205.84; HRMS: m/z calcd for $C_{11}H_{12}O_2$ 176.0837. Found 176.0825.

1-9 References and Notes

1. M. Pereyre, J. -P. Quintard and A. Rahm, *Tin in Organic Synthesis*, Butterworth & Co., London, 1987, p. 286.
2. J. E. McMurry and J. Melton, *J. Am. Chem. Soc.*, 1971, **93**, 5309; E. Baltazzi and L. I. Krimen, *Chem. Rev.*, 1963, **63**, 511; D. E. Wolf and K. Folkers, *Org. React.*, 1951, **6**, 410; G. A. Molander and S. W. Andrews, *Tetrahedron Lett.*, 1989, **30**, 2351.
3. I. Pri-Bar, P. S. Pearlman and J. K. Stille, *J. Org. Chem.*, 1983, **48**, 4629.
4. M. Kosugi, I. Takano, M. Sakurai, H. Sano and T. Migita, *Chem. Lett.*, 1984, 1221.
5. J. H. Simpson and J. K. Stille, *J. Org. Chem.*, 1985, **50**, 1759.
6. Y. Watanabe, T. Yoneda, Y. Ueno and T. Toru, *Tetrahedron Lett.*, 1990, **31**, 6669.

7. A. Baba, H. Kishiki, I. Shibata and H. Matsuda, *Organometallics*, 1985, **4**, 1329; A. Baba, I. Shibata, H. Kashiwagi and H. Matsuda, *Bull. Chem. Soc. Jpn.*, 1986, **59**, 341; I. Shibata, A. Baba, H. Iwasaki and H. Matsuda, *J. Org. Chem.*, 1986, **51**, 2177.
8. I. Shibata, T. Imoto, A. Baba and H. Matsuda, *J. Heterocycl. Chem.*, 1987, **24**, 361; A. Baba and H. Matsuda, *J. Chem. Soc., Chem. Commun.*, 1986, 1703.
9. K. Kobayashi, M. Kawanishi, T. Hitomi and S. Kozima, *Chem. Lett.*, 1984, 497.
10. T. A. Geissman and R. I. Akawie, *J. Am. Chem. Soc.*, 1951, **73**, 1993; J. J. Riehl, A. Smolikiewicz and L. Thil, *Tetrahedron Lett.*, 1974, 1451; D. A. Holt, *Tetrahedron Lett.*, 1981, **22**, 2243.
11. J. Holecek, M. Nadvornik, K. Handlir and A. Lycka, *J. Organomet. Chem.*, 1983, **241**, 177; M. Nadvornik, J. Holecek, K. Handlir and A. Lycka, *J. Organomet. Chem.*, 1984, **275**, 43.
12. P. Z. Bedoukian, *J. Am. Chem. Soc.*, 1945, **67**, 1430.
13. P. Duhamel, L. Duhamel and J. -Y. Valnot, *Bull. Soc. Chim. Fr.*, 1973, 1465.
14. M. Pereyre, B. Bellegarde, J. Mendelsohn and J. Valade, *J. Organomet. Chem.*, 1968, **11**, 97.
15. M. A. Baig, D. V. Banthorpe, G. Carr and D. Whittaker, *J. Chem. Soc., Perkin Trans. 2*, 1989, 1981.
16. J. P. Schaefer, *J. Org. Chem.*, 1960, **25**, 2027.
17. W. M. Best and D. A. Widdowson, *Tetrahedron*, 1989, **45**, 5943.
18. S. Wollowitz and J. Halpern, *J. Am. Chem. Soc.*, 1988, **110**, 3112.
19. I. Shibata, M. Nishio, A. Baba, H. Matsuda, *Chem. Lett.*, 1993, 1219.
20. I. Shibata, M. Nishio, A. Baba, H. Matsuda, *J. Chem. Soc., Chem. Commun.*, **1993**, 1067.
21. In contrast to 2-bromoheptanal (**8a**), the reaction of 2-chloroheptanal with **12** afforded the adduct derived from addition at the carbonyl group.[7]

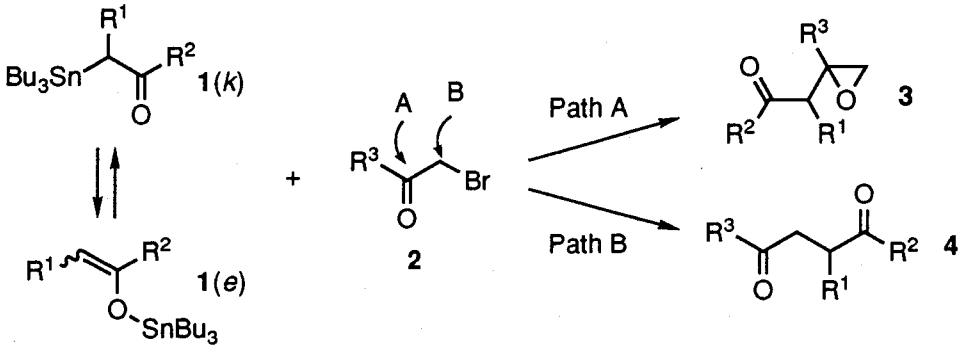
Chapter 2

NMR Studies of Five-Coordinate Tin Enolate: An Efficient Reagent for Halo Selective Reaction toward α-Halo Ketone or α-Halo Imine

2-1 Introduction

Organotin reagents have been extensively studied in the context of carbon-carbon bond formation.[1] Of particular interest are organotin enolates, which couple with electrophiles such as carbonyl compounds[2] and organic halides.[3] The α-halo ketones **2**, which have both types of electrophilic moiety inherently react with tin enolates **1** at the carbonyl carbon. For example, the reaction of **1a** and 2-bromoacetophenone **2a** at 63 °C for 20 h was reported to give β-keto oxirane **3aa** in 79% yield (Scheme 1, Path A),[4] and was further accelerated by the addition of a Pd-catalyst.[4] Migita and co-workers have also reported that various types of tin enolates, including **1a-c**, attack α-halo ketones selectively at the carbonyl moiety, furnishing substituted furans *via* intermediate oxiranes **3**.[5]

Scheme 1



a: R^1 = H, R^2 = Me
b: R^1 = H, R^2 = Ph
c: -R^1-R^2- = -$(CH_2)_4$-
d: R^1 = H, R^2 = *t*-Bu

In contrast, we have reported the reverse general chemoselectivity in the high coordination of tin enolates **1** with appropriate ligands such as HMPA, Bu_3PO and Bu_4NBr, in which 1,4-diketones **4** were predominantly produced *via* coupling at the halide moiety of **2** (Path B) under mild, nearly neutral conditions.[6] In this halo selective reaction, we have assumed that a five-coordinate tin enolate is generated and plays a key role, but no confirming evidence has been obtained. The complete change of chemoselectivity was largely dependent on the tin enolates and the ligands employed, and in several cases, a small amount of product due to coupling at the carbonyl moiety of α-halo ketones was observed. Organotin enolates **1** usually exist as mixtures of *C*-stannyl ketone **1**(*k*) and *O*-stannyl enolate **1**(*e*), as shown in Scheme 1.

In this report, NMR studies of tin enolates in the presence of HMPA confirm the presence of high-coordinate *O*-stannyl enolates **1**(*h*), which may promote the reverse chemoselectivity. In addition, we describe a completely selective coupling at the halide moiety with tin enolates and α-halo imines, which are considered to be masked α-halo ketones.[7]

2-2 NMR Studies of High-Coordinate Tin Enolate

In order to confirm the presence of high-coordinate tin enolates, three representative tin enolates **1a**, **1b** and **1c** were analyzed by ^{1}H, ^{13}C and ^{119}Sn NMR spectrometry, under conditions similar to those of the practical synthesis of 1,4-diketones, noted in Table 2. Two types of NMR samples were prepared: (i) a 1 M solution of tin compound **1** in C_6D_6; (ii) a 1 M C_6D_6 solution of **1** plus 1.5 equiv of HMPA. Table 1 summarizes the results of the ^{119}Sn NMR analyses. When no ligand was added, the ratios of the keto and enol forms were greatly dependent on their substituents, as shown in Table 1-(i). Tin enolate **1a** existed primarily in the keto form and **1c** exclusively in the enol form, in C_6D_6. Both forms were present in the case of tin enolate **1b**. Similar results have been reported by M. Pereyre.[8] ^{119}Sn NMR spectra of **1** showed peaks at *ca.* 0 ppm and 100 ppm, corresponding to **1**(*k*) and **1**(*e*), respectively.

Table 1. Ratios of Tin Compounds **1(*k*, *e* and *eh*)** and ^{119}Sn NMR Chemical Shifts (δ, ppm)

			1a			**1b**			**1c**		
			k^a	e^a	eh^a	k^a	e^a	eh^a	k^a	e^a	eh^a
(i)[b]	without	ratio (%)	92	8	-	74	26	-	0	100	-
	HMPA	δ(^{119}Sn)	-3.6	92.7	-	1.4	104.0	-	-	91.0	-
(ii)[b]	HMPA	ratio (%)	79	0	21	33	0	67	0	0	100
		δ(^{119}Sn)	-3.8	-	6.7	1.3	-	-11.0	-	-	43.5

[a] *k*; Keto form, *e*; enol form, *eh*; statistical average of enol form and coordinated enol form.
[b] (i) Tin compd **1** in C_6D_6 (1 M). (ii) Adding 1.5 equiv of HMPA to 1 M of C_6D_6 solution of **1**.

Table 2. Reaction of Tin Enolate **1a-c** with 2-Bromoacetophenone **(2a)**[a]

				% yield			
entry	tin enolate	ligand	conditions	**4**		**3**	
1	**1a**	—	80 °C, 1 h	**4aa**	0	**3aa**	90
2	**1a**	HMPA	25 °C, 1 h	**4aa**	73	**3aa**	12
3	**1b**	—	80 °C, 4 h	**4ba**	4	**3ba**	34(27)[b]
4	**1b**	HMPA	25 °C, 4 h	**4ba**	70	**3ba**	0(22)[c]
5	**1c**	—	80 °C, 5 h	**4ca**	22	**3ca**	50
6	**1c**	HMPA	25 °C, 1 h	**4ca**	56	**3ca**	0
7	**1c**	Bu_4NBr	25 °C, 1.5 h	**4ca**	76	**3ca**	0

[a] All reactions were performed using tin enolate (3.6 mmol), ligand (5.4 mmol), and 2-bromoacetophenone (3.0 mmol) in dry benzene (3 mL). [b] The formation of bromohydrin derivative **3ba-1** *via* carbonyl attack was accompanied. [c] Yield of 2,4-diphenylfuran derivative by rearrangement of oxirane (Padmanabhan, S.; Ogawa, T.; Suzuki, H. *Bull. Chem. Soc. Jpn.* **1989**, *62*, 2114).

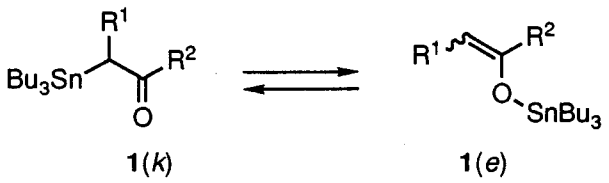
Table 2 shows the results of the reaction between the tin enolates **1a-c** and 2-bromoacetophenone **2a**. In the absence of ligands, tin enolates preferably attacked the carbonyl group of **2a** to give β-keto oxirane **3** or bromohydrin. These results precluded the idea that keto and enol forms attack the carbonyl and halide moieties, respectively, because **1c**, present as only the enol form, gave predominantly the corresponding β-keto

oxirane. The chemoselectivity toward the carbonyl moiety appears to be independent of the form of the tin enolate. On the other hand, the addition of HMPA or Bu_4NBr (1.5 equiv) caused a dramatic change of chemoselectivity and produced 1,4-diketones **4** by attack at the halide carbon with all three tin enolates examined. As shown in Table 1-(ii), NMR analyses of the tin enolates in the presence of HMPA (1.5 equiv) revealed the following features: (1) the percentage of keto form (*k*) was decreased, although no change in its chemical shift $\delta(^{119}Sn)$ was observed; (2) the signals for the enol form (*e*) disappeared, and broad signals (*eh*), corresponding to the statistical average of (*e*) and (*h*), appeared at higher field. It is reasonable to suggest that the five-coordinate tin enolate species (*h*) are also responsible for the change of chemoselectivity.

The data in Table 3, which lists ^{13}C and ^{1}H NMR chemical shifts for **1a-c**(*k*, *e* and *eh*), suggest that **1**(*eh*) are enol forms because of the presence of signals due to vinylic carbons (C-5 and C-6) and protons (5-H). In addition, the larger coupling constants $^{1}J(^{119}Sn\text{-}^{13}C)$ (Table 4) and considerable upfield shifts in the ^{119}Sn NMR spectra relative to those of **1**(*e*) (Table 1) suggest that the species for five-coordinate *O*-stannyl enolates **1**(*h*) are present[9] and contribute to the equilibrium. As a consequence, HMPA would coordinate not to *C*-stannyl ketones **1**(*k*), but exclusively to *O*-stannyl enolates **1**(*e*), to lead to the decrease in the percentage of keto form **1**(*k*) as shown in Scheme 2.

Scheme 2

(i) Without Ligand



1(*k*) **1**(*e*)

(ii) With Ligand

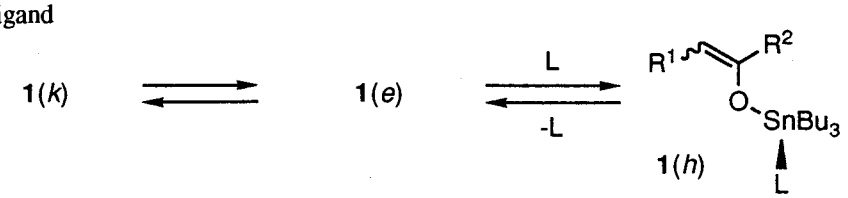
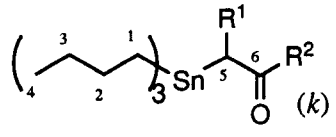
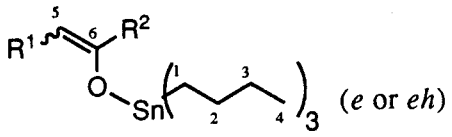


Table 3. ^{13}C and ^{1}H NMR Chemical Shifts (δ, ppm) of Tin Compounds **1**





	1a			**1b**			**1c**		
position	*k*	*e*	*eh*	*k*	*e*	*eh*	*k*	*e*	*eh*
^{13}C NMR									
C-1	10.4	15.6	17.7	10.8	15.9	18.4	-	15.6	16.9
C-2	29.2	28.2	28.6	29.1	28.2	28.7	-	28.3	28.5
C-3	27.5	27.4	27.6	27.5	27.4	27.7	-	27.4	27.5
C-4	13.8	[a]	14.0	13.8	[a]	14.0	-	13.9	13.9
C-5	29.6	84.0	81.8	25.4	84.9	82.1	-	96.7	95.6
C-6	204.4	163.5	164.2	198.1	162.6	163.4	-	157.4	157.8
others		*Me*C=O			aroma			ring	
	30.3	24.1	25.0	138.9	140.7	142.8	-	24.9	25.1
				132.0	128.1	127.7		24.6	24.4
				128.5	127.8	126.9		23.6	23.8
				128.2	126.0	126.1			
^{1}H NMR[b]									
5-H	2.17(s)	3.92(s)	3.83(s)	2.77(s)	4.74(d, 1.1)	4.65(s)	-	4.59(t, 3.7)	4.60(t, 3.7)
		3.78(s)	3.77(s)		4.13(d, 1.1)	4.12(s)			
others		*Me*C=O			aroma			ring	
	2.00(s)	2.07(s)	2.07(s)		8.1-7.8[c](m)	8.2-7.9[d](m)	-	2.3(m)	2.32(m)
					7.4-7.1[c](m)	7.4-7.2[d](m)	-	1.9-1.5(m)	1.9-1.5(m)

[a] Obscured by other signals. [b] Multiplicity and coupling constant in parentheses. [c] Mixture of **1b**(*k*) and **1b**(*e*). [d] Mixture of **1b**(*k*) and **1b**(*eh*).

Table 4. ^{119}Sn - ^{13}C Coupling Constants ($^{n}J_{SnC}$, Hz) of Tin Compounds **1**

	1a			**1b**			**1c**		
	k	*e*	*eh*	*k*	*e*	*eh*	*k*	*e*	*eh*
$^{1}J_{SnC}$	330.9	362.2	445.8	330.0	359.4	464.2	-	360.3	409.1
$^{2}J_{SnC}$	21.1	[a]	25.7	21.1	21.1	[a]	-	21.1	22.1
$^{3}J_{SnC}$	57.9	[a]	[a]	57.0	58.8	[a]	-	64.4	67.1

[a] Obscured by other signals.

The resulting five-coordinate *O*-stannyl enolates **1**(*h*) effected the selective formation of 1,4-diketones. Moreover, the reactivity was considerably enhanced by the coordination. The enolate **1**(*h*) underwent the addition even at room temperature, in contrast to **1**(*e*) for which heating was required (Table 2, entries 1, 3 and 5). The larger difference of $\delta(^{13}C)$ between C-5 and C-6 in **1**(*eh*) relative to that in **1**(*e*) indicates a higher degree of polarization at the reaction site in **1**(*h*), leading to the facile coupling reaction under mild conditions.

Increasing the amount of HMPA led to an increase in both the percentage of enol form and the degree of hypervalency of the tin center, as depicted in Figure 1 and 2 respectively.[9]

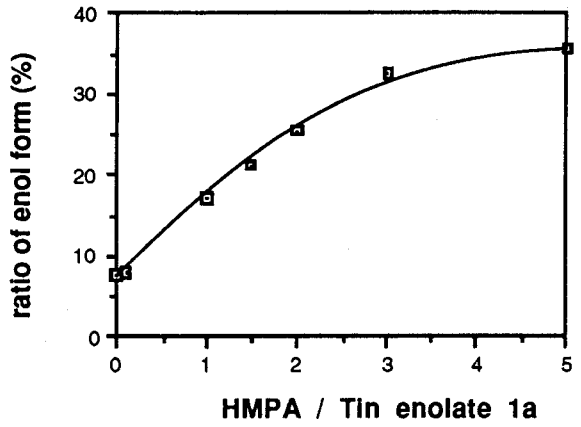


Figure 1. Correlation of the raio of enol form with equivalents of HMPA to tin enolate **1a**.

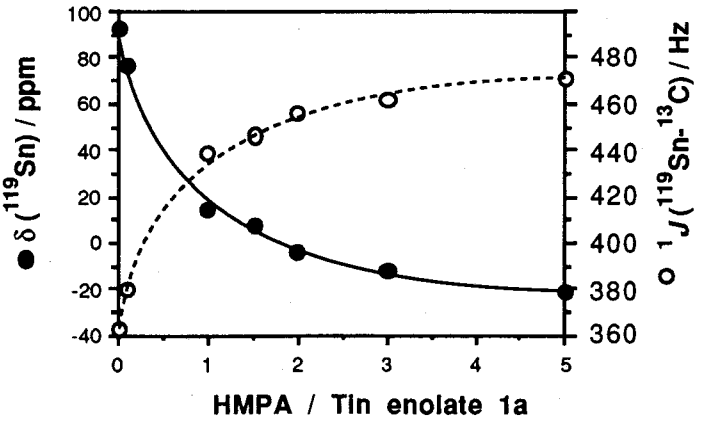


Figure 2. Correlation of the raio of chemical shift $\delta(^{119}Sn)$ and coupling constant $^{1}J(^{119}Sn\text{-}^{13}C)$ with equivalents of HMPA to tin enolate **1a**.

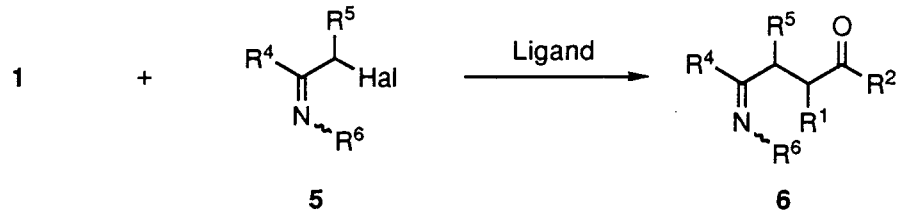
The ratio of the $^1J(^{119}Sn\text{-}^{13}C)$ value (470.6 Hz) of **1a** with 5.0 equiv of HMPA to that of **1a** (362.2 Hz) without HMPA is 1.30, which is close to the theoretical ratio of 1.33[9b] for five-coordinate to four-coordinate tin. Accordingly, the equilibrium between (*e*) and (*h*) lies well toward the five-coordinate tin enolate (*h*), when 5 equiv of HMPA is present. As already reported, 5 equiv of HMPA gave 1,4-diketone **4aa** exclusively, from **1a** and **2a**,[6] and this is consistent with our suggestion that five-coordinate tin enolate **1**(*h*) is responsible for the change of chemoselectivity. The best yield of 1,4-diketone **4aa**, however, was obtained in the presence of 1.5 equiv of HMPA.[6] The degree of hypervalency increased only slightly in the presence of greater than 1 equiv of HMPA, as shown in Figure 2. Excess "free" HMPA might even prevent the interaction of five-coordinate tin enolate with **2a**.

On the other hand, an attempt to confirm the presence of Bu_4NBr-coordinated enolates was unsuccessful. In NMR studies, signals corresponding to *C*-stannyl derivatives were absent, and no signals for *O*-stannyl species were detected either,[11] perhaps due to an instability of the resulting coordinated enolates. A considerably higher yield of 1,4-diketone **4ca**, in fact, was obtained with Bu_4NBr (entry 7 in Table 2). In the next section, another application of Bu_4NBr to this general system is discussed.

2-3 Reaction of Five-Coordinate Organotin Enolates with α-Halo Imines

In the synthesis of 1,4-diketones from high-coordinate tin enolates and α-bromo ketones, the formation of oxiranes could not be completely suppressed in many cases. In order to overcome this complication, we attempted the coupling with α-halo imines **5** instead of α-halo ketones. The α-halo imines are readily available from the corresponding α-halo carbonyl compounds.[7,11] We anticipated that the lower reactivity of imino moieties relative to carbonyl groups might lead to a selective coupling at the halide moieties of **5** (Scheme 3).

Scheme 3



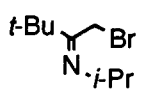
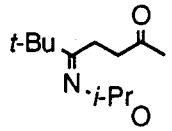
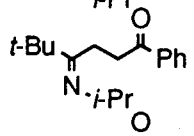
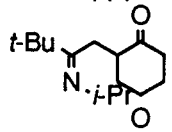
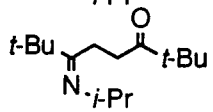
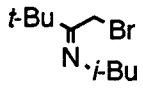
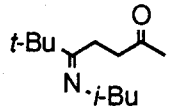
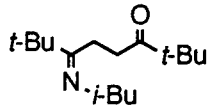
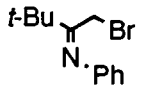
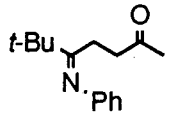
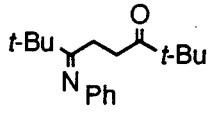
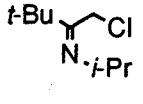
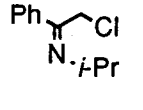
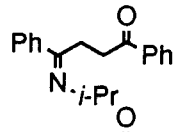
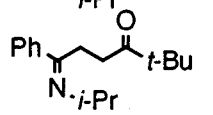
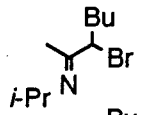
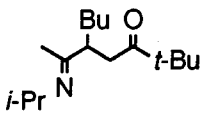
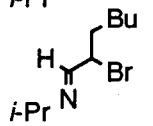
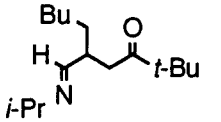
Employing **1a** and **5a** (R^4 = *t*-Bu, R^5 = H, R^6 = *i*-Pr), various reaction conditions were examined, as shown in Table 5. Although HMPA and Bu_3PO had an impact on the reaction only at elevated temperature (entries 8 and 9), Bu_4NBr efficiently promoted the selective synthesis of γ-imino ketone **6aa** even at room temperature (entry 4). Neither Et_4NBr nor Me_4NBr showed activity, even in refluxing THF, because of their low solubility. Most effective was 1.5 equiv of Bu_4NBr in THF.

Table 5. Effect of Ligands and Solvents in the Reaction of **1a** and α-Bromo Imine **5a**[a]

entry	solvent	ligand	ligand/ **1a**	temp, °C	time, h	% yield of **6aa**
1	THF	—	—	63	45	0
2	THF	Bu_4NBr	0.1	63	21	16
3	THF	Bu_4NBr	1.0	25	1	69
4	THF	Bu_4NBr	1.5	25	2.5	80
5	THF	Bu_4NBr	2.5	25	4	59
6	THF	Et_4NBr	1.5	63	17.5	2
7	THF	Me_4NBr	1.5	63	17.5	0
8	THF	HMPA	1.5	63	3.5	66
9	THF	Bu_3PO	1.5	63	23	47
10	C_6H_6	Bu_4NBr	1.5	25	8	60
11	C_6H_6	Bu_4NBr	1.5	80	1	79
12	CH_3CN	Bu_4NBr	1.5	25	8	41
13	$(CH_2Cl)_2$	Bu_4NBr	1.5	25	22.5	25

[a] Raction conditions: tin enolate **1a** (3.6 mmol), α-bromo imine **5a** (3.0 mmol), ligand (0-2.5 equiv), solvent (3 mL).

Table 6. Synthesis of γ-Imino Ketone **6** from Tin Enolate **1** and α-Halo Imine **5**[a]

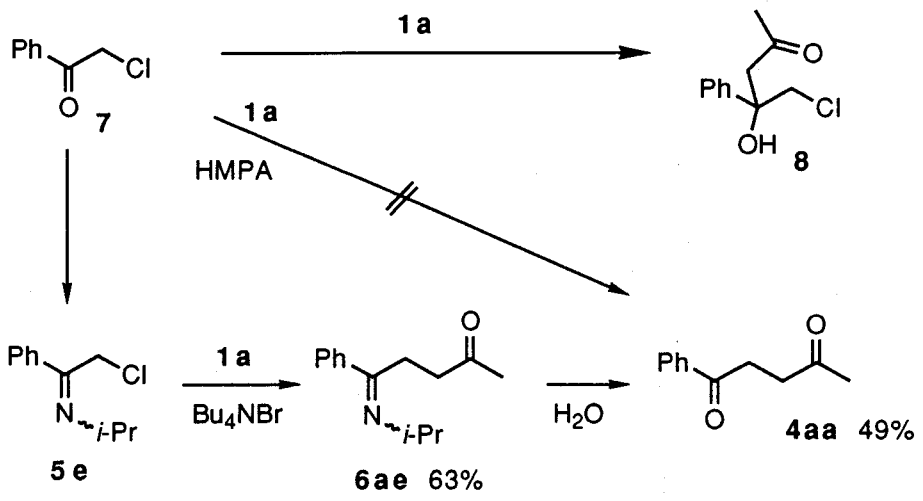
entry	tin enolate	α-halo imine	time, h	product	% yield
1	**1a**	 **5a**	2.5	 **6aa**	80
2	**1b**		2.5 1	 **6ba**	52[b] 63[c]
3	**1c**		16	 **6ca**	98
4	**1d**		17	 **6da**	90
5	**1a**	 **5b**	8	 **6ab**	43
6	**1d**		22	 **6db**	77
7	**1a**	 **5c**	8	 **6ac**	41
8	**1d**		7	 **6dc**	92
9	**1a**	 **5d**	4	**6aa**	52
10	**1b**		1	**6ba**	40[b]
11	**1c**		2	**6ca**	72[b]
12	**1d**		20	**6da**	53
13	**1b**[d]	 **5e**[e]	2	 **6be**	51[f]
14	**1d**		2	 **6de**	65[b, g]
15	**1d**[d]	 **5f**	8	 **6df**	54[b]
16	**1d**[d]	 **5g**	8	 **6dg**	57[c]

[a] Reaction conditions: tin enolate **1** (3.6 mmol), α-halo imine **5** (3.0 mmol), Bu_4NBr (5.4 mmol), solvent THF (3 mL), 25 °C. [b] 63 °C.
[c] Solvent benzene (3 mL), 80 °C. [d] Tin enolate **1** (6.0 mmol), Bu_4NBr (9.0 mmol).
[e] *E* / *Z* = 1 / 1. [f] *E* / *Z* = 4 / 7. [g] *E* / *Z* = 3 / 2.

Table 6 summarizes the synthesis of γ-imino ketones **6** from various types of tin enolates **1a-d** and α-halo imines **5a-g**. α-Halo imines proved to be less active than the parent α-halo ketones as exemplified by the observation that bromopinacolone, the parent ketone of **5a**, was readily activated, even by HMPA, to couple with **1a** in 79% yield,[6] while **5a** was activated only by Bu_4NBr. In no case were products due to attack on an imino carbon detected. The synthetic potential of the efficient coupling of α-chloro imines **5d** and **5e**, or α-bromo aldimine **5g** is noteworthy, since the coupling reaction with both parent α-halo carbonyls took place only at their carbonyl moieties, furnishing chlorohydrins[4] or oxiranes,[6] respectively.

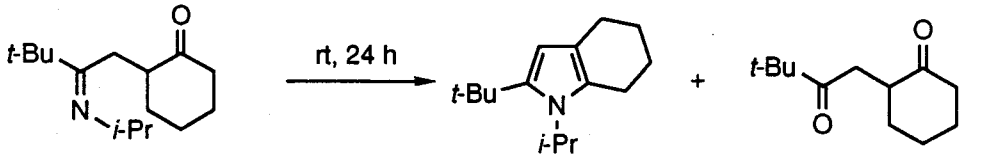
Scheme 4 illustrates the transformation of 2-chloroacetophenone **7** to 1,4-diketone **4aa** (49% yield based on **7**) *via* hydrolysis of the imino ketone **6ae**, which was confirmed by ^1H NMR spectroscopy.[12] An attempt to directly synthesize **4aa** from **1a** and **7** was unsuccessful and led to the exclusive formation of **8**. Similarly 1,4-diketone **4da** (R^1 = H, R^2 = *t*-Bu, R^3 = Ph) was isolated in 45% yield after direct silica gel chromatography of the reaction mixture of **1d** and **5e**.

Scheme 4



It was found that some product imino ketones gradually converted to substituted pyrroles, which were formed by intramolecular attack of nitrogen on the carbonyl carbon, and subsequent dehydration.

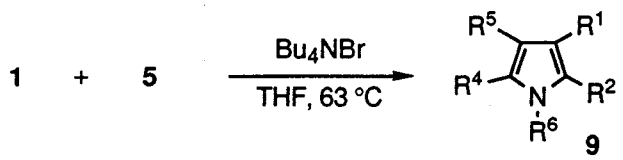
Scheme 5



6ca **9ca** 43% **10** 55%

For example, **6ca** was converted to pyrrole **9ca** (43%), along with 1,4-diketone **10** (55%), upon standing at room temperature for 24 h (Scheme 5). Imino ketones bearing *tert*-butyl groups at their carbonyl carbons are not transformed into pyrroles. On the other hand, when the substituent R^6 has *syn* orientation to R^4, as in the case of α-halo imine **5f** and **5g**, the cyclization to a pyrrole was observed. Thus, the degree of steric congestion around the imino nitrogen dictates the outcome. Using these *syn*-halo imines, direct syntheses of substituted pyrroles **9** were attained as shown in Table 7.

Table 7. Synthesis of Pyrrole **9** from Tin Enolate **1** and α-Bromo Imine **5**[a]



		α-bromo imine					pyrrole	
entry	tin enolate		R^4	R^5	R^6	time, h	yield, %	
1	**1a**	**5f**	Me	*n*-Bu	*i*-Pr	6	**9af**	32
2	**1a**	**5g**	H	*n*-pentyl	*i*-Pr	24	**9ag**	45
3	**1b**	**5g**	H	*n*-pentyl	*i*-Pr	69	**9bg**	31
4	**1c**	**5g**	H	*n*-pentyl	*i*-Pr	2	**9cg**	43

[a] Reaction conditions: tin enolate **1** (3.6 mmol), α-bromo imine **5** (3.0 mmol), Bu_4NBr (5.4 mmol), THF (3 mL), 63 °C.

The Paar-Knorr procedure gives substituted pyrroles from 1,4-diketones with amines under vigorous conditions.[13] Wittig has also reported the direct formation of pyrroles *via* the addition of lithium N-vinylamide to α-halo imines at -78°C.[14] Our high-coordination method provides alternative, convenient access to pyrroles under much milder conditions.

2-4 Experimental Section

General. Melting points were taken on a Yanagimoto melting point apparatus and are uncorrected. IR spectra were recorded as thin films or as solids in KBr pellets on a Hitachi 260-30 spectrophotometer. ^{1}H and ^{13}C NMR spectra were obtained with a Hitachi R-90H (90 and 400 MHz) or a JEOL JNM-GSX-400 (400 and 100 MHz) spectrometer, respectively with TMS as internal standard. Mass spectra were recorded on a JEOL JMS-DS303 or a Shimadzu GCMS-QP2000A spectrometer. GLC analyses were performed on a Shimadzu GC-8A with FID using a 2 m × 3 mm column packed with SE-52. Flash chromatography was performed on silica gel (Wakogel C-300). Bulb-to-bulb distillation (Kugelrohr) was accomplished in a Sibata GTO-250RS at the oven temperature and pressure indicated. Yields were determined by GLC or ^{1}H NMR using internal standards.

Materials. THF and benzene were distilled from sodium and benzophenone. HMPA was distilled from CaH_2. Tin enolates **1a-d** were prepared by known methods.[8]

2-Bromoacetophenone **2a**, 1-bromopinacolone, 1-chloropinacolone and 2-chloroacetophenone were commercial products. 3-Bromoheptan-2-one[15] and 2-bromoheptanal[16] were prepared according to described methods. α-Halo imines **5a**, **5d** and **5e** were prepared by condensation of the corresponding α-halo ketones with isopropylamine.[7] Other α-halo imines **5b**, **5f** and **5g** were also prepared in accordance with the described methods.[7] α-Halo imines **5** were unstable and used immediately for further reaction.

Preparation and Measurement of NMR Samples. The samples (i) were

prepared from tin enolates **1** (0.4 mmol) in C_6D_6 (0.4 mL) and the samples (ii) from tin enolates **1** (0.4 mmol) and HMPA (0.6 mmol) in C_6D_6 (0.4 mL). ^{119}Sn NMR spectra were recorded at room temperature on a JEOL JNM-GSX-400 (149 MHz) with Me_4Sn as internal standard.

General Procedure for Synthesis of 1,4-Diketones (4) and β-Keto Oxiranes (3). These synthetic methods and the spectral data of compounds **4aa**, **4ba**, **4ca** and **3aa** were described in our previous paper[6] and **4da** in the literature.[17]

2-Phenacyl-2-phenyloxirane (3ba). Obtained from **1b** and **2a** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 5:1): IR (neat) 1700 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 8.0-7.2 (m, 10H), 3.78 (dd, 1H, J = 16.61, 0.98 Hz), 3.59 (d, 1H, J = 16.61 Hz), 3.12 (d, 1H, J = 4.89 Hz), 2.98 (dd, 1H, J = 4.89, 0.98 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 195.9, 139.4, 136.4, 132.9, 128.2, 127.94, 127.87, 127.3, 125.4, 56.7, 54.9, 44.9; MS m / z 238 (M^+); HRMS calcd for $C_{16}H_{14}O_2$ 238.0994, found m / z 238.0979 (M^+).

2-(2-Oxo-cyclohexyl)-2-phenyloxirane (3ca). Obtained from **1c** and **2a** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 5:1): IR (neat) 1700 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.46-7.22 (m, 5H), 2.97 (d, 1H, J = 4.88 Hz), 2.89 (d, 1H, J = 4.88 Hz), 2.51-1.41 (m, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 209.5, 138.2, 128.9, 127.5, 127.4, 59.4, 58.7, 54.8, 42.1, 29.6, 26.5, 24.5; MS m / z 216 (M^+); Anal. Calcd for $C_{14}H_{16}O_2$: C, 77.45; H, 7.46. Found: C, 77.51; H, 7.62.

2-(3,3-Dimethyl-2-oxo-butyl)cyclohexanone (10). ^1H NMR (400 MHz, $CDCl_3$) δ 3.05 (dd, 1H, J = 17.58, 6.83 Hz), 2.98 (m, 1H), 2.38 (t, 2H, J = 4.88 Hz), 2.23 (dd, 1H, J = 17.58, 4.89 Hz), 2.17-2.03 (m, 2H), 1.87-1.59 (m, 3H), 1.41-1.21 (m, 1H), 1.17 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 214.1, 211.4, 46.1, 44.1, 41.9, 36.6, 34.1, 28.0, 26.5, 25.4; HRMS calcd for $C_{12}H_{20}O_2$ 196.1463, found m / z 196.1435 (M^+).

4-Bromo-3-hydroxy-1,3-diphenylbutan-1-one (3ba-1). A mixture of tin

enolate **1b** (2.04 g, 5.0 mmol) and 2-bromoacetophenone **2a** (0.80g, 4.0 mmol) in dry THF (4 mL) was stirred at room temperature under nitrogen for 5 h. This reaction mixture was added to diethyl ether (100 mL) and aqueous NH_4F (15%; 40 mL) stirring for 1 h and washed with water (50 mL × 2), dried ($MgSO_4$) and evaporated. The residue was flash chromatographed and title compound **3ba-1** (eluted by hexane-diethyl ether, 5:1) was isolated as an oil in 42% yield: IR (neat) 3450, 1670 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 8.0-7.0 (m, 10H), 4.98 (s, 1H), 3.94 (d, 1H, J = 17.36 Hz), 3.70 (s, 2H), 3.66 (d, 1H, J = 17.36 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 200.2, 143.1, 136.7, 133.5, 128.4, 128.2, 127.9, 127.4, 125.0, 74.7, 45.2 (t, $^1J_{CH}$ = 126.8 Hz, C-2), 42.8 (t, $^1J_{CH}$ = 152.7 Hz, C-4). Satisfactory high resolution mass spectral and elemental analysis data for the title compound **3ba-1** could not be obtained due to its instability. IR, ^1H and ^{13}C NMR data were in good analogy[6] with those of 4-chloro-3-hydroxy-1,3-diphenylbutan-1-one or 5-bromo-4-hydroxy-4-phenylpentan-2-one.

N-(1-Bromo-3,3-dimethyl-2-butylidene)isobutylamine (5b). To a mixture of 1-bromopinacolone (50 mmol) and $TiCl_4$ (30 mmol) in 80 mL of diethyl ether was added dropwise a solution of isobutylamine (200 mmol) in 20 mL of diethyl ether at 0 °C, the mixture was stirred for 3 h at room temperature, and 0.5 N NaOH (100 mL) was added to the reaction mixture. It is then filtered and water layer was extracted with diethyl ether. After drying over $MgSO_4$ and evaporation of solvent, the crude product was purified by distillation at reduced pressure (63% yield): bp 64 °C/ 2 mmHg; IR (neat) 1640 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.78 (s, 2H), 3.21 (d, 2H, J = 6.84 Hz) 2.02-1.92 (m, 1H), 1.19 (s, 9H), 0.94 (d, 6H, J = 6.84 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 169.6, 58.7, 40.8, 29.8, 28.3, 20.6, 17.2; MS m / z 235 (M^+ + 2), 233 (M^+); HRMS calcd for $C_{10}H_{20}NBr$ 233.0779, found m / z 233.0774 (M^+).

N-(1-Bromo-3,3-dimethyl-2-butylidene)aniline (5c). The preparation of **5c** was analogous to that described for the synthesis of **5b**. The title compound was obtained from 1-bromopinacolone (50 mmol) and aniline (200 mmol) in the presence of $TiCl_4$ (30 mmol) in 46% yield: bp 74 °C/ 2 mmHg; IR (neat) 1600 cm^{-1}; ^1H NMR (90

MHz, $CDCl_3$) δ 7.6-6.6 (m, 5H), 3.77 (s, 2H), 1.45 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 173.3, 150.0, 128.6, 123.1, 118.3, 40.0, 28.8, 18.8; MS *m / z* 253 (M^+), 251 (M^+ - 2); HRMS calcd for $C_{12}H_{16}NBr$ 253.0466, found *m / z* 253.0465(M^+).

N-(3-Bromo-2-heptylidene)isopropylamine (5f). The preparation of **5f** was analogous to that described for the synthesis of **5b**. The title compound was obtained from 3-bromoheptan-2-one (50 mmol) and isopropylamine (200 mmol) in the presence of $TiCl_4$ (30 mmol) in 80% yield: bp 42 °C/ 1 mmHg; IR (neat) 1660 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 4.43 (t, 1H, *J* = 7.81 Hz), 3.64 (septet, 1H, *J* = 6.35 Hz), 1.94 (s, 3H), 1.5-1.2 (m, 6H), 1.12 (d, 1H, *J* = 6.35 Hz), 1.10 (d, 1H, *J* = 6.35 Hz), 0.90 (t, 3H, *J* = 6.84 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 163.6, 60.6, 50.6, 35.5, 29.8, 22.0, 23.0, 22.8, 13.7; MS *m / z* 236 (M^++ 3), 234 (M^+ + 1); HRMS calcd for $C_{10}H_{20}NBr$ 233.0779, found *m / z* 234.0878 (M^++1).

N-(2-Bromo-1-heptylidene)isopropylamine (5g). The preparation of **5g** was analogous to that described for the synthesis of **5b**. The title compound was obtained from 2-bromoheptanal (50 mmol) and isopropylamine (200 mmol) in the presence of $TiCl_4$ (30 mmol) in 55% yield: bp 54 °C/ 2 mmHg; IR (neat) 1660 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.59 (d, 1H, *J* = 7.04 Hz), 4.41 (dt, 1H, *J* = 7.04, 7.03 Hz), 3.37 (septet, 1H, *J* = 6.37 Hz), 2.2-0.7 (m, 11H), 1.16 (d, 6H, *J* = 6.37 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 159.2, 60.3, 54.0, 35.6, 31.0, 26.9, 23.8 and 23.5 (2 × NCH*Me*), 22.3, 13.8; MS *m / z* 235 (M^+ +2), 233 (M^+); HRMS calcd for $C_{10}H_{20}NBr$ 233.0779, found *m / z* 233.0797 (M^+).

General Procedure for Synthesis of γ-Imino Ketones (6). A mixture of a tin enolate (3.6 mmol) and an additive (5.4 mmol) in dry solvent (3 mL) was stirred for 10 min under nitrogen. To this solution was added an α-halo imine (3.0 mmol), and stirring under the reaction conditions noted in Tables VI. Volatiles were removed under reduced pressure, solids precipitated on addition of hexane. Hexane layer is then pipeted out. The treatment was repeated a few times and the collected hexane solution was evaporated. Kugelrohr distillation gave the γ-imino ketone **6**. The configurations of **6**

were assigned as follows. α-Halo imines **5a-d** (R^4 = *t*-Bu) having *Z*-form (*t*-Bu and R^6 are *anti*-configuration) prepared in accordance with the described methods[7] coupled with **1** at halide moiety to form (*E*)-γ-imino ketones **6aa**, **6ba**, **6ca**, **6da**, **6ab**, **6db**, **6ac** and **6dc** (*t*-Bu and R^6 are *anti*-configuration). All these *anti* isomers showed ^{13}C NMR chemical shifts δ($^{13}CH_2C$=N) at *ca.* 21-25 ppm. There are considerable differences in the chemical shifts δ($^{13}CH_2C$=N) of two isomers of **6be** and **6de**, respectively, which are *ca.* 22 ppm and 35 ppm. Thus, the formers were identified to be *E*-isomers (Ph and *i*-Pr are *anti*-configuration) and the latters were *Z*-isomers (*syn*) by comparison with the data of **6** bearing *t*-Bu at R^4 (*anti*). **5f** and **5g**, and their products (**6df** and **6dg**) could be determined to have *E*-form because of sterical hindrance.[7]

N-(6,6-Dimethyl-2-oxo-5-heptylidene)isopropylamine (6aa). Obtained from **1a** and **5a** according to the general procedure by distillation: bp 60 °C/2 mmHg; IR (neat) 1730, 1660 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.54 (septet, 1H, *J* = 6.34 Hz), 2.54-2.44 (m, 4H), 2.16 (s, 3H), 1.08 (s, 9H), 1.06 (d, 6H, *J* = 6.34 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 206.5, 172.1, 49.8, 42.0, 40.4, 29.8, 28.1, 23.9, 20.7; MS *m* / *z* 197 (M^+), 140 (M^+ - C_4H_9); HRMS calcd for $C_{12}H_{23}NO$ 197.1780, found *m* / *z* 197.1775 (M^+). Anal. Calcd for $C_{12}H_{23}NO$: C, 73.04; H, 11.75; N, 7.01. Found: C, 72.66; H, 11.74; N, 6.67.

N-(5,5-Dimethyl-1-oxo-1-phenyl-4-hexylidene)isopropylamine (6ba). Obtained from **1b** and **5a** according to the general procedure by distillation to afford **6ba** as solid, bp 90 °C/ 0.07 mmHg, mp 70.5 °C (from hexane); IR (neat) 1680, 1640 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.94 (m, 2H), 7.4-7.6 (m, 3H), 3.63 (septet, 1H, *J* = 6.35 Hz), 3.08-3.04 (m, 2H), 2.67-2.63 (m, 2H), 1.13 (s, 9H), 1.10 (d, 6H, *J* = 6.35 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 198.1, 172.3, 136.1, 133.1, 128.5, 127.8, 49.9, 40.4, 37.0, 28.1, 24.0, 21.0; MS *m* / *z* 259 (M^+), 202 (M^+ - C_4H_9). Anal. Calcd for $C_{17}H_{25}NO$: C, 78.72; H, 9.71; N, 5.40. Found: C, 78.84; H, 9.78; N, 5.42.

[3,3-Dimethyl-1-(2-oxo-cyclohexyl)-2-butylidene]isopropylamine (6ca). Obtained from **1c** and **5a** according to the general procedure by distillation: bp

100 °C/2 mmHg; IR (neat) 1700, 1640 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.57 (septet, 1H, *J* = 6.10 Hz), 2.70 (dd, 1H, *J* = 13.91, 3.90 Hz), 2.36 (dd, 1H, *J* = 13.91, 10.01 Hz), 1.08 (s, 9H), 0.99 (d, 6H, *J* = 6.10 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 211.5, 171.9, 50.0, 49.5, 42.2, 40.2, 33.9, 28.9, 27.9, 25.63, 25.58, 24.0 and 23.9 (2 × NCH*Me*). Satisfactory high resolution mass spectral and elemental analysis data for the title compound **3ba-1** could not be obtained due to its rapid cyclization to pyrrole **9ca**.

N-(2,2,7,7-Tetramethyl-3-oxo-6-octylidene)isopropylamine (6da). Obtained from **1d** and **5a** according to the general procedure by distillation: bp 90 °C/0.1 mmHg; IR (neat) 1710, 1650 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.53 (septet, 1H, *J* = 6.35 Hz), 2.57-2.51 (m, 2H), 2.47-2.41 (m, 2H), 1.15 (s, 9H), 1.08 (s, 9H), 1.07 (d, 6H, *J* = 6.35 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 213.6, 172.4, 49.6, 43.8, 40.1, 34.9, 27.9, 26.3, 23.8, 21.0; MS *m* / *z* 239 (M^+), 182 ($M^+ - C_4H_9$); HRMS calcd for $C_{15}H_{29}NO$ 239.2249, found *m* / *z* 239.2253 (M^+). Anal. Calcd for $C_{15}H_{29}NO$: C, 75.26; H, 12.21; N, 5.85. Found: C, 75.64; H, 11.83; N, 5.89.

N-(6,6-Dimethyl-2-oxo-5-heptylidene)isobutylamine (6ab). Obtained from **1a** and **5b** according to the general procedure by distillation: bp 85 °C/1 mmHg; IR (neat) 1720, 1640 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 3.06 (d, 2H, *J* = 6.37 Hz), 2.51 (s, 4H), 2.16 (s, 3H), 1.6-2.1 (m, 1H), 1.10 (s, 9H), 0.90 (d, 6H, *J* = 6.59 Hz); ^{13}C NMR (400 MHz, $CDCl_3$) δ 206.8, 175.6, 58.5, 40.9, 40.6, 30.0, 29.7, 27.9, 20.9, 20.5; MS *m* / *z* 211 (M^+), 154 ($M^+ - C_4H_9$); HRMS calcd for $C_{13}H_{25}NO$ 211.1936, found *m* / *z* 211.1926 (M^+).

N-(2,2,7,7-Tetramethyl-3-oxo-6-octylidene)isobutylamine (6db). Obtained from **1d** and **5b** according to the general procedure by distillation: bp 60 °C/0.05 mmHg; IR (neat) 1710, 1650 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.06 (d, 2H, *J* = 6.84 Hz), 2.57-2.45 (m, 4H), 2.01-1.80 (m, 1H), 1.15 (s, 9H), 1.10 (s, 9H), 0.90 (d, 6H, *J* = 6.84 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 213.9, 176.1, 58.5, 44.1, 40.9, 33.7, 30.1, 27.9, 26.4, 21.5, 20.6; MS *m* / *z* 253 (M^+), 196 ($M^+ - C_4H_9$); HRMS calcd for $C_{16}H_{31}NO$ 253.2406, found *m* / *z* 253.2409 (M^+). Anal. Calcd for $C_{16}H_{31}NO$: C,

75.83; H, 12.33; N, 5.53. Found: C, 75.51; H, 12.05; N, 5.14.

N-(6,6-Dimethyl-2-oxo-5-heptylidene)aniline (6ac). Obtained from **1a** and **5c** according to the general procedure by distillation: bp 120 °C/1 mmHg; IR (neat) 1720, 1650 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.43-6.68 (m, 5H), 2.80-2.77 (m, 2H), 2.70-2.67 (m, 2H), 2.20 (s, 3H), 1.17 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 205.8, 178.9, 151.1, 128.8, 122.4, 118.3, 40.9, 40.7, 29.2, 27.8, 22.4; MS *m* / *z* 231 (M^+), 174 ($M^+ - C_4H_9$); HRMS calcd for $C_{15}H_{21}NO$ 231.1623, found *m* / *z* 231.1642 (M^+).

N-(2,2,7,7-Tetramethyl-3-oxo-6-octylidene)aniline (6dc). Obtained from **1d** and **5c** according to the general procedure by distillation: bp 120 °C/0.1 mmHg; IR (neat) 1710, 1650 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.19 (m, 2H), 6.89 (m, 1H), 6.59 (m, 2H) 2.46-2.29 (m, 4H), 1.16 (s, 9H), 0.85 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) d 213.5, 179.5, 151.3, 128.8, 122.4, 118.5, 43.8, 41.0, 33.7, 27.8, 26.1, 23.1; MS *m* / *z* 273 (M^+), 216 ($M^+ - C_4H_9$); HRMS calcd for $C_{18}H_{27}NO$ 273.2093, found *m* / *z* 273.2071 (M^+). Anal. Calcd for $C_{18}H_{27}NO$: C, 79.07; H, 9.95; N, 5.12. Found: C, 78.98; H, 9.62; N, 5.21.

N-(1,4-Diphenyl-1-oxo-4-butylidene)isopropylamine (6be). Obtained from **1b** and **5e** according to the general procedure by distillation. It was isolated as a mixture of (*E*)- and (*Z*)-**6be** (*E* / *Z* = 4 / 7) which showed bp 150 °C/0.1 mmHg, mp 87-90 °C (from hexane); IR (KBr) 1680, 1650 cm^{-1}; MS *m* / *z* 279 (M^+), 222 ($M^+ - C_4H_9$); HRMS calcd for $C_{19}H_{21}NO$ 279.1623, found *m* / *z* 279.1611 (M^+). Anal. Calcd for $C_{19}H_{21}NO$: C, 81.68; H, 7.58; N, 5.01. Found: C, 81.55; H, 7.55; N, 4.91. ^1H NMR (400 MHz, $CDCl_3$) δ 8.06-7.15 (aroma, *E* and *Z*), (*E*)-**6be** 3.23 (septet, 1H, *J* = 6.35 Hz), 3.13-3.09 (m, 4H), 1.24 (d, 6H, 6.35 Hz), (*Z*)-**6be** 3.43 (septet, 1H, *J* = 6.10 Hz), 3.29 (t, 2H, *J* = 6.93 Hz), 2.93 (t, 2H, *J* = 6.93 Hz), 0.95 (d, 6H, 6.10 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 199.5 (s, C-1, *E* and *Z*), 166.1 and 164.5 (s, C-4, *Z* and *E*), 139.3, 137.6, 132.9, 132.3, 129.1, 128.4, 128.2, 127.9, 127.8, 127.7, 126.9, 126.0 (aroma), 51.7 and 51.0 (d, NC, *Z* and *E*), 36.1 and 34.4 (t, C-2, *E* and *Z*), 35.7

and 22.7 (t, C-3, *Z* and *E*), 24.0 and 23.8 (q, CH*Me*$_2$, *E* and *Z*). Further recrystallizing from hexane gave single isomer (*Z*)-**6be** as white crystals, mp 87.5 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06-7.15 (m, 10H), 3.41 (septet, 1H, *J* = 6.11 Hz), 3.30 (t, 2H, *J* = 6.93 Hz), 2.93 (t, 2H, *J* = 6.93 Hz), 0.96 (d, 6H, *J* = 6.11 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 199.9, 166.6, 139.3, 137.6, 132.6, 128.4, 128.1, 127.9, 126.1, 51.9, 35.7, 34.5, 23.8.

N-(2,2-Dimethyl-3-oxo-6-phenyl-6-hexylidene)isopropylamine (6de). Obtained from **1d** and **5e** according to the general procedure by distillation. It was isolated as a mixture of (*E*)- and (*Z*)-**6de** (*E* / *Z* =3 / 2) which showed bp 110 °C/0.1 mmHg; IR (neat) 1710, 1650 cm^{-1}; MS *m* / *z* 259 (M+), 202 (M+ - C_4H_9); HRMS calcd for $C_{17}H_{25}NO$ 259.1936, found *m* / *z* 259.1915 (M$^+$). Anal. Calcd for $C_{17}H_{25}NO$: C, 78.72; H, 9.71; N, 5.40. Found: C, 78.53; H, 9.69; N, 5.09. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.01-7.13 (aroma, *E* and *Z*), (*E*)-**6de** 3.39 (septet, 1H, *J* = 6.35 Hz), 2.84 (t, 2H, *J* = 6.59 Hz), 2.70 (t, 2H, *J* = 6.59 Hz), 1.23 (d, 6H, 6.35 Hz), 1.17 (s, 9H), (*Z*)-**6de** 3.12 (septet, 1H, *J* = 6.35 Hz), 2.94 (t, 2H, *J* = 7.82 Hz), 2.59 (t, 2H, *J* = 7.82 Hz), 1.09 (d, 6H, 6.35 Hz), 1.07 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 214.7 (s, C-3, *E* and *Z*), 166.7 and 165.1 (s, C-6, *E* and *Z*), 139.9 and 139.6 (s, ipso, *E* and *Z*), 129.1, 128.2, 127.6, 126.8, 126.0 (aroma), 51.7 and 50.9 (d, NC, *E* and *Z*), 43.9 (s, C-2, *E* and *Z*), 34.9 (t), 34.1 (t), 32.4 (t), 26.7 (q, C*Me*$_3$), 26.3 and 23.9 (q, CH*Me*$_2$, *Z* and *E*), 22.7 (t, C-5, *E*)

N-(5-Butyl-2,2-dimethyl-3-oxo-6-heptylidene)isopropylamine (6df). Obtained from **1d** and **5f** according to the general procedure by distillation: bp 80 °C/0.1 mmHg; IR (neat) 1700, 1660 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.58 (septet, 1H, *J* = 6.35 Hz), 3.16 (dd, 1H, *J* = 17.82, 10.01 Hz), 2.69 (m, 1H), 2.36 (dd, 1H, *J* = 17.82, 4.15 Hz), 1.86 (s, 3H), 1.52-0.86 (m, 9H), 1.12 (s, 9H), 1.00 (d, 6H, *J* = 6.35 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 215.2, 168.2, 49.8, 44.3, 43.7, 39.8, 32.8, 29.4, 26.6, 23.4, 22.8, 17.6, 13.9; MS *m* / *z* 254 (M$^+$ + 1), 168 (M$^+$ - *t*-BuCO); HRMS calcd for $C_{16}H_{31}NO$ 253.2406, found *m* / *z* 253.2430 (M$^+$).

N-(2,2-Dimethyl-3-oxo-5-pentyl-6-hexylidene)isopropylamine (6dg). Obtained from **1d** and **5g** according to the general procedure by distillation: bp 110 °C/0.1 mmHg; IR (neat) 1710, 1670 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.65 (d, 1H, *J* = 4.88 Hz), 3.24 (septet, 1H, *J* = 6.35 Hz), 2.88 (dd, 1H, *J* = 17.09, 7.82 Hz), 2.81-2.73 (m, 1H), 2.48 (dd, 1H, *J* = 17.09, 5.37 Hz), 1.5-0.78 (m, 11H), 1.14 (s, 9H), 1.10 (d, 6H, *J* = 6.35 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 214.6, 164.1, 61.1, 44.0, 39.2, 39.1, 32.3, 31.8, 26.7, 26.5, 24.0, 22.5, 13.9; MS *m* / *z* 253 (M^+), 196 (M^+ - C_4H_9); HRMS calcd for $C_{16}H_{31}NO$ 253.2406, found *m* / *z* 253.2434 (M^+).

General Procedure for Synthesis of Substituted Pyrroles (9). A mixture of a tin enolate (3.6 mmol) and an additive (5.4 mmol) in dry solvent (3 mL) was stirred for 10 min under nitrogen. To this solution was added an α-haloimine (3.0 mmol), and stirred under the reaction conditions noted in Table 7. Volatiles were removed under reduced pressure, diethyl ether (100 mL) and aqueous NH_4F (15%; 40 mL) were added and the resulting Bu_3SnF was filtered off. The filtrate was washed with water (50 mL × 2), dried ($MgSO_4$) and evaporated. Flash chromatography of the resultant residue on silica gel gave the substituted pyrrole **9**.

3-Butyl-1-isopropyl-2,5-dimethylpyrrole (9af). Obtained from **1a** and **5f** according to the general procedure by flash chromatography (eluted by hexane-dietyl ether, 99:1): IR (neat) 2920, 780 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 5.65 (s, 1H), 4.38 (septet, 1H, *J* = 7.32 Hz), 2.32 (t, 2H, *J* = 7.81 Hz), 2.26 (s, 3H), 2.18 (s, 3H), 1.53-1.15 (m, 4H), 1.45 (d, 6H, *J* = 7.32 Hz), 0.91 (t, 3H, *J* = 7.32 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 126.0, 123.0, 119.3, 106.8, 47.0, 33.7, 25.9, 22.8, 22.3, 14.04, 14.00, 11.1; MS *m* / *z* 193 (M^+), 150 (M^+ - C_3H_7); HRMS calcd for $C_{13}H_{23}N$ 193.1830, found *m* / *z* 193.1840 (M^+). Anal. Calcd for $C_{13}H_{23}N$: C, 80.76; H, 11.99; N, 7.24. Found: C, 80.61; H, 11.64; N, 6.93.

1-Isopropyl-5-methyl-3-pentylpyrrole (9ag). Obtained from **1a** and **5g** according to the general procedure by distillation: bp 75 °C/1 mmHg; IR (neat) 2900, 1660, 780 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 6.43 (s, 1H), 5.71 (s, 1H), 4.18

(septet, 1H, J = 6.83 Hz) 2.40 (t, 2H, J = 7.81 Hz), 2.19 (s, 3H), 1.58-1.13 (m, 6H), 1.37 (d, 6H, J = 6.83 Hz), 0.89 (t, 3H, J = 7.32 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 127.2, 123.2, 111.9, 106.4, 46.6, 32.0, 31.0, 27.3, 23.6, 22.6, 14.1, 12.0; MS m / z 193 (M^+), 150 (M^+ - C_3H_7); HRMS calcd for $C_{13}H_{23}N$ 193.1830, found m / z 193.1840 (M^+).

1-Isopropyl-5-phenyl-3-pentylpyrrole (9bg). Obtained from **1b** and **5g** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 4:1): IR (neat) 2900, 1710, 770 cm^{-1}; ^{1}H NMR (90 MHz, $CDCl_3$) δ 7.4-7.1 (m, 5H), 6.63 (s, 1H), 5.98 (s, 1H), 4.43 (septet, 1H, J = 6.59 Hz), 2.49 (t, 2H, J = 7.36 Hz), 1.7-1.1 (m, 6H), 1.36 (d, 6H, J = 6.59 Hz), 0.91 (t, 1H, J = 5.94 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 134.2, 133.7, 129.0, 128.2, 126.5, 124.6, 114.4, 108.7, 47.0, 32.0, 30.8, 27.4, 24.0, 22.6, 14.1; MS m / z 255 (M^+), 212 (M^+ - 43); HRMS calcd for $C_{18}H_{25}N$ 255.1987, found m / z 255.1974 (M^+). Anal. Calcd for $C_{18}H_{25}N$: C, 84.65; H, 9.87; N, 5.48. Found: C, 84.88; H, 10.11; N, 5.55.

1-Isopropyl-3-pentyl-tetrahydrobenzopyrrole (9cg). Obtained from **1c** and **5g** according to the general procedure by flash chromatography (eluted by hexane): IR (neat) 2900, 1700, 720 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.39 (s, 1H), 4.14 (septet, 1H, J = 6.84 Hz), 2.52 (t, 2H, J = 6.11 Hz), 2.43 (t, 2H, J = 6.11 Hz), 2.35 (t, 2H, 7.81 Hz), 1.84-1.70 (m, 4H), 1.58-1.51 (m, 2H), 1.49-1.39 (m, 4H), 1.36 (d, 6H, J = 6.84 Hz), 0.90 (t, 3H, J = 6.83 Hz); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 126.7, 121.2, 115.7, 111.0, 46.3, 32.1, 30.2, 25.7, 23.7, 23.6, 23.5, 22.6, 22.1, 21.7, 14.1; MS m / z 233 (M^+), 190 (M^+ - C_3H_7); HRMS calcd for $C_{16}H_{27}N$ 233.2143, found m / z 233.2129 (M^+). Anal. Calcd for $C_{16}H_{27}N$: C, 82.34; H, 11.66; N, 6.00. Found: C, 82.53; H, 11.80; N, 5.79.

1-Isopropyl-2-*tert*-butyl-tetrahydrobenzopyrrole (9ca). Obtained from **1c** and **5a** according to the general procedure by flash chromatography (eluted by hexane-dietyl ether, 1:1): IR (neat) 2930, 780 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.65 (s, 1H), 4.76 (septet, 1H, J = 6.84 Hz), 2.73 (t, 2H, J = 6.11 Hz), 2.50 (t, 2H, J = 6.34

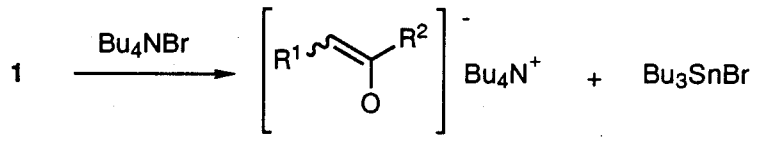
Hz), 1.83-1.67 (m, 4H), 1.46 (d, 6H, J = 6.84 Hz), 1.36 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 139.6, 127.4, 116.4, 102.8, 47.4, 32.0, 31.3, 25.4, 24.2, 23.5, 23.3, 22.1; MS m / z 219 (M^+), 162 (M^+ - C_4H_9); HRMS calcd for $C_{15}H_{25}N$ 219.1987, found m / z 219.1971 (M^+).

2-5 References and Notes

1. Pereyre,M.; Quintard, J.-P.; Rahm, A. *Tin in Organic Synthesis*, Butterworth, London, **1987**.
2. (a) Noltes, J. G.; Creemers, H. M. J. C.; Van Der Kerk, G. J. M. *J. Organomet. Chem.* **1968**, *11*, 21. (b) Labadie, S. S.; Stille, J. K. *Tetrahedron* **1984**, *40*, 2329. (c) Yamamoto, Y.; Yatagi, H.; Maruyama, K. *J. Chem. Soc., Chem. Commun.* **1981**, 162.
3. (a) Odic, Y.; Pereyre, M. *J. Organomet. Chem.* **1973**, *55*, 273. (b) Jung, M. E.; Blum, R. B. *Tetrahedron Lett.* **1977**, *43*, 3791. (c) Kosugi, M.; Hagiwara, I.; Sumiya, T.; Migita, T. *Bull. Chem. Soc. Jpn.* **1984**, *57*, 242. (d) Kosugi, M.; Hagiwara, I.; Migita, T. *Chem. Lett.* **1983**, 839. (e) Kosugi, M.; Koshiba, M.; Atoh, A.; Sano, H.; Migita, T. *Bull Chem. Soc. Jpn.* **1986**, *59*, 677.
4. Pri-Bar, I.; Pearlman, P. S.; Stille, J. K. *J. Org. Chem.***1983**, *48*, 4629.
5. Kosugi, K.; Takano, I.; Hoshino, I.; Migita, T. *J. Chem. Soc., Chem. Commun.* **1983**, 989.
6. (a) Baba, A.; Yasuda, M.; Yano, K.; Shibata, I.; Matsuda, H. *J. Chem. Soc., Perkin Trans. 1* **1990**, 3205. (b) Yasuda, M.; Oh-hata, T.; Shibata, I.; Baba, A.; Matsuda, H. *J. Chem. Soc., Perkin Trans. 1* **1993**, 859.
7. De Kimpe, N.; De Cock, W.; Stevens, C. *Tetrahedron* **1992**, *48*, 2739.
8. Pereyre, M; Bellegarde, B; Mendelsohn, J; Valade, J. *J. Organometal. Chem.* **1968**, *11*, 97.
9. In general, an increase of coordination number of tin compounds from four to five causes an upfield shift of δ(^{119}Sn) and high values of coupling constants ^nJ(^{119}Sn-

^{13}C). For example, see: (a) Holecek, J.; Nadvornik, M.; Handlir, K. *J. Organomet. Chem.* **1983**, *241*, 177. (b) Nadvornik, M.; Holecek, J.; Handlir, K. *J. Organomet. Chem.* **1984**, *275*, 43.

10. The generation of the naked enolate anion also may be considered in terms of the following equation, as proposing its formation by attack of fluoride ion at silicon in silyl enolate. For example, see: (a) Nakamura, E.; Shimizu, M.; Kuwajima, I.; Sakata, J.; Yokoyama, K.; Noyori, R. *J. Org. Chem.* **1983**, *48*, 932. (b) Chuit, C.; Corriu, R. J. P.; Reyé, C. *J. Organomet. Chem.* **1988**, *358*, 57. In our NMR examination of the mixture of tin enolate **1a-c** and Bu_4NBr, however, the signals for neither Bu_3SnBr nor its complex with Bu_4NBr, $[Bu_3SnBr_2]^- Bu_4N^+$, was observed.



11. De Kimpe, N.; Verhe, R.; De Buyck, L.; Moens, L.; Schamp, N. *Synthesis* **1982**, 43.

12. γ-Imino ketone **6ae** could not be isolated and crude reaction mixture included two regioisomers (6 : 4) which showed ^1H NMR (90 MHz, $CDCl_3$) δ 3.87 (septet, J = 6.3 Hz, NH), 3.1-2.5 (m, CH_2CH_2), 2.10 (s, *Me*CO), 1.22 (d, J = 6.3 Hz, $CHMe_2$) and 3.39 (septet, J = 6.3 Hz, NH), 2.73 (s, CH_2CH_2), 2.19 (s, *Me*CO), 1.00 (d, J = 6.3 Hz, $CHMe_2$).

13. (a) Paal, C. *Chem. Ber.* **1884**, *17*, 2756. (b) Knorr, L. *Chem. Ber.* **1884**, *17*, 2863.

14. Wittig, G.; Roderer, R.; Fischer, S. *Tetrahedron Lett.* **1973**, 3517.

15. Bedoukian, P. Z. *J. Am. Chem. Soc.* **1945**, *67*, 1430.

16. Duhamel, P.; Duhamel, L.; Valnot, J.-Y. *Bull. Soc. Chim. Fr.* **1973**, 1465.

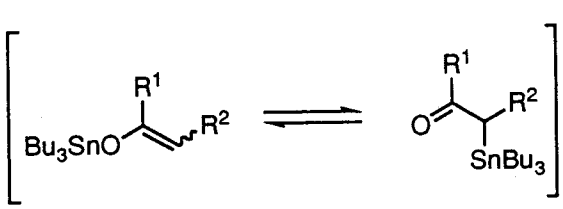
17. Russell, G. A.; Kulkarni, S. V.; Khanna, R. K. *J. Org. Chem.* **1990**, *55*, 1080.

Chapter 3

A Catalytic Effect of Five-Coordinate Organotin Bromide or Tetraphenylstibonium Bromide on Chemo- and Stereoselective Addition of Tin Enolate to α-Halo Ketone

3-1 Introduction

An organotin enolate is one of the most versatile tools for carbon-carbon bond formation.[1,2] Of particular interest is the addition to carbonyl compounds.[3] Organotin enolates **1** exist as tautomeric mixtures of keto- and/or enol-forms,[4] and the large dependence of the ratio on their substituents and conditions disturbs frequently the unified reaction modes.



	R^1	R^2
1a	Me	H
1b	Ph	H
1c	*t*-Bu	H
1d	-$(CH_2)_4$-	

Scheme 1

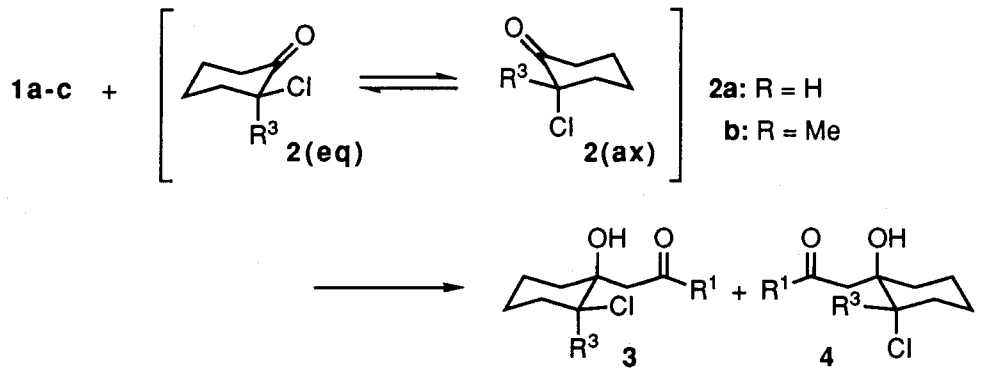
We recently demonstrated that the coordination to tin atom increases the ratio of the enol form, and that the resulting high-coordinate tin enolates are effective reagents for halo selective reaction toward α-halo carbonyls.[5] On the other hand, a fine carbonyl-selective addition was reported[6] by Stille and co-workers to finally produce 2-(2-oxoethyl)oxiranes, where a palladium catalyst is indicated to act as a Lewis acid, and the possibility of an oxidative addition of palladium (0) with the carbon-halogen bond is excluded. This fact indicates that a mild Lewis acid like palladium (II) is appropriate to activate the carbonyl group in the presence of an acid-sensitive tin enolate.

In the course of investigation utilizing high-coordinate tin enolates,[7] we found an example for the formation of 2-(2-oxoethyl)oxiranes from 2-bromo-1-phenylethanone

and tin enolate **1a** in the presence of Bu_3SnBr-Bu_4NBr or Bu_3SnBr-HMPA.[7b] In addition, we have recently discovered[8] that tetraphenylstibonium bromide[9] (Ph_4SbBr) catalytically promoted a highly stereoselective addition of tin enolates to 2-chlorocycloalkanones. These two types of catalysts both plausibly activate the carbonyl function in α-halo ketones. In the previous works, we have found some examples that high-coordinate Bu_3SnI complexes and Ph_4SbI acted as similar catalysts in the reaction of CO_2 with oxirane[10] or oxetane.[11] Moreover, in the cycloaddition of monosubstituted oxiranes and heterocumulenes, both Ph_4SbI[12] and Bu_3SnI-Bu_3PO[13] were found to catalyze the unusual cleavage of oxirane rings at the substituted site. In this paper, we focus on the analogous activity of five-coordinate tributyltin bromides and tetraphenylstibonium bromide as catalysts for the formation of 2-(2-oxoethyl)oxiranes *via* chemoselective addition of tin enolate **1** to carbonyl groups of α-halo ketones.

3-2 Diastereoselective Addition to 2-Chlorocyclohexanones

Control of the stereochemistry in nucleophilic addition to substituted cyclic ketones is a current subject in organic syntheses.[14] As briefly reported,[8] Ph_4SbBr-catalyst could control the stereoselective addition of tin enolate **1** to 2-chlorocyclohexanone (**2a**). Because **2** exists as a mixture of conformers, **2(eq)** and **2(ax)**, in the comparable ratios as shown in Scheme 2,[15] isomeric mixtures **3** and **4** (for example, **3aa/4aa** = 48/52) were obtained under noncatalyzed conditions.



Scheme 2

The effects of catalysts for the reaction of **1** with **2** are summarized in Table 1. The combination catalysts of tributyltin bromide (Bu_3SnBr) with such onium salts as Bu_4NBr, Bu_4PBr and Ph_4SbBr effected the exclusive formation of chlorohydrin derivative **3aa**. These onium bromides alone gave lower yields of **3aa** except Ph_4SbBr. The sole use of Bu_3SnBr only lead to the similar result to that of noncatalyzed run (entries 8 and 1). It is notable that Bu_3SnBr-onium salt showed the similar catalytic effect to Ph_4SbBr alone.

Table 1. Effect of Catalyst in the Reaction of Tin Enolates **1** with 2-Chlorocyclohexanones **2**[a)]

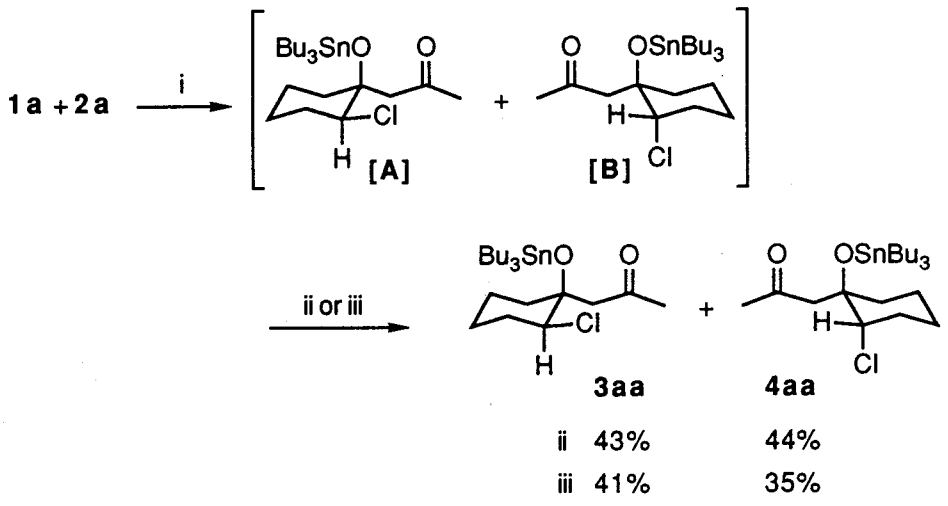
Entry	Tin enolate	Chloroketone	Catalyst	Yield/%	Ratio
					3 : **4**
1	**1a**	**2a**	none	**aa:** 95	48 : 52
2	**1a**	**2a**	Bu_4NBr	**aa:** 24	100 : —
3	**1a**	**2a**	Bu_4PBr	**aa:** 24	97 : 3
4	**1a**	**2a**	Ph_4SbBr	**aa:** 68	95 : 5
5	**1a**	**2a**	Bu_3SnBr-Bu_4NBr	**aa:** 59	100 : —
6	**1a**	**2a**	Bu_3SnBr-Bu_4PBr	**aa:** 44	97 : 3
7	**1a**	**2a**	Bu_3SnBr-Ph_4SbBr	**aa:** 70	100 : —
8	**1a**	**2a**	Bu_3SnBr	**aa:** 85	50 : 50
9	**1b**	**2a**	none	**ba:** 100	60 : 40
10	**1b**	**2a**	Ph_4SbBr	**ba:** 75	100 : —
11	**1c**	**2a**	none	**ca:** 79	63 : 37
12	**1c**	**2a**	Ph_4SbBr	**ca:** 44	100 : —
13	**1a**	**2b**	none	**ab:** 56	82 : 18
14	**1a**	**2b**	Ph_4SbBr	**ab:** 91	100 : —

a) Tin enolate **1** (6.0 mmol), chloro ketone **2** (3.0 mmol), catalyst (0.3 mmol), THF (3 mL), 40 °C, 24 h.

We should consider the equilibrium in the addition step for tin enolate to carbonyl carbon, resulting in the isomerization caused by Ph_4SbBr between intermediate tin halo alkoxides **[A]** and **[B]**. Following experiments excluded the presence of the isomerization (Scheme 3). The reaction of **1a** with **2a** in THF at 40 °C for 12 h afforded

3aa (43%) and **4aa** (44%) after hydrolysis of **[A]** and **[B]**, respectively. While without hydrolysis, further stirring for 12 h after adding of a catalytic amount of Ph_4SbBr gave little change of selectivity (41% of **3aa** and 35% **4aa**).

These results apparently showed the absence of isomerization between **[A]** and **[B]**, and suggested the direct face-control of the direction of the nucleophilic addition, where exclusive equatorial and axial attacks would be controlled in the equatorial-chloro-**2(eq)** and axial-chloro form **2(ax)**, respectively, furnishing the adduct **3** finally.

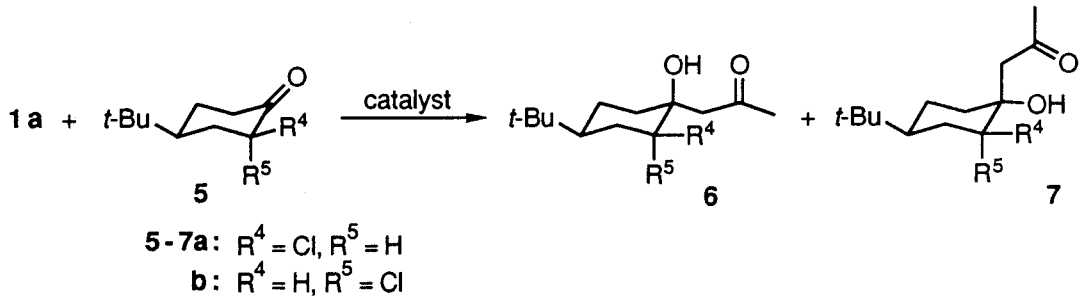


Reagents and conditions:
(i) 40 °C, 12 h, THF; (ii) H_2O; (iii) Ph_4SbBr (0.1 equiv), 40 °C, 12 h, and then H_2O.

Scheme 3

Next, more details were investigated by using sterically fixed conformers, *cis*- and *trans*-4-*tert*-butyl-2-chlorocyclohexanones (**5a** and **5b**) (Scheme 4, Table 2). Equatorial attack to **5a** was exclusive irrespective of the presence of a catalyst to produce **6a** as already reported.[8] In contrast, **5b** was completely controlled to only the axial attack by Ph_4SbBr or Bu_3SnBr-Bu_4NBr, furnishing the adduct **7b** with *cis*-conformation for chloro and hydroxy groups, while in the absence of the catalyst, a mixture of adducts arising from equatorial and axial attack (75/25) was obtained. In this case too, Ph_4SbBr and Bu_3SnBr-Bu_4NBr showed a similar catalytic activity as shown in Table 2 (entries 4 and 5).

Scheme 4



5-7a: $R^4 = Cl, R^5 = H$
b: $R^4 = H, R^5 = Cl$

Table 2. Stereoselectivity in the Addition of **1a** to **5**[a)]

Entry	Chloroketone		Catalyst	Yield/%	Ratio
	5 R^4	R^5			**6** : **7**
1 **a:**	Cl	H	none	76	100 : —
2 **a:**	Cl	H	Ph_4SbBr	61	100 : —
3 **b:**	H	Cl	none	72	75 : 25
4 **b:**	H	Cl	Ph_4SbBr	60	— : 100
5 **b:**	H	Cl	Bu_3SnBr-Bu_4NBr	71	— : 100

a) Tin enolate **1a** (6.0 mmol), chloro ketone **5** (3.0 mmol), catalyst (0.3 mmol), THF (3 mL), 40 °C, 24 h.

The interaction between onium salts and Bu_3SnBr was examined by ^{119}Sn NMR spectroscopy as listed in Table 3. The signal for Bu_3SnBr was remarkable moved to upfield by the addition of Bu_4NBr or Bu_4PBr. These upfield shifts indicate the formation of five-coordinate tin species coordinated by a bromide anion.[16] These tin species have trigonal bipyramidal structures with the substituent Br and the ligand Br in both axial positions,[16a] in which the original Sn-Br bond becomes some ionically. On the contrary, the relative small shift of $\delta(^{119}Sn)$ in entry 4 indicates small interaction between Bu_3SnBr and Ph_4SbBr. This small shift is in good accordance with the fact that Ph_4SbBr acted as a catalyst with little assistance of Bu_3SnBr in the addition step to the carbonyl moiety (entries 4 and 7 in Table 1).

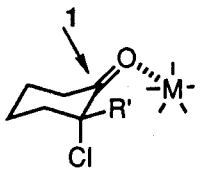
Table 3. ^{119}Sn NMR Chemical Shifts of Bu_3SnBr Effected by Onium Salt.[a)]

Entry	Tin compound (complex)	$\delta(^{119}Sn)$/ppm
1	Bu_3SnBr	106
2	Bu_3SnBr-Bu_4NBr	-34
3	Bu_3SnBr-Bu_4PBr	-26
4	Bu_3SnBr-Ph_4SbBr	84

a) The samples were prepared from Bu_3SnBr (0.125 mmol) and onium salt (0.125 mmol) in THF (0.4 mL) and THF-d_8 (0.1 mL).

This weak coordination ability of Ph_4SbBr is explained in terms of the low-ionic Sb-Br bond[17] in comparison with the other onium bromides which have typical ionic bonds. Tetraphenylstibonium bromide is also known to have a trigonal bipyramidal structure in which the Sb-Br bond occupies an axial position.[17] Structural and bonding analogy between tetraphenylstibonium bromide and five-coordinate organotin bromide may be responsible for the similar catalytic activities.

This catalytic stereocontrol could be rationalized by the rate acceleration effect of these organometallics because a facile addition to the carbonyl moiety took place without any catalysts. We assume that these catalysts would act as Lewis acids and cause unusual addition to **2(ax)**, where the coordinating carbonyl group and axial chlorine prevent the equatorial attack of tin enolate as illustrated in Scheme 5.

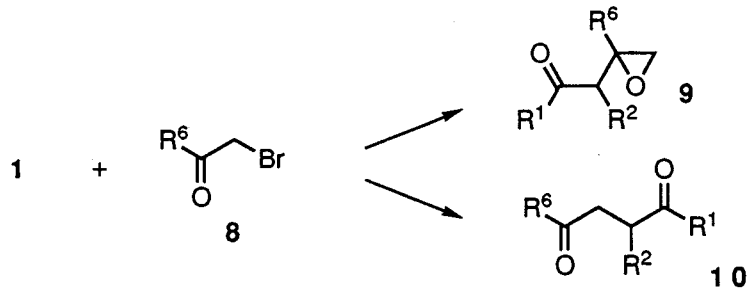


Scheme 5

Although details are not clear, the catalytic cycle could be accomplished owing to both appropriate Lewis acidity and lower oxo-affinity in comparison with other metals like Al reported by Yamamoto.[18]

3-3 Application to Oxirane Formation

Stille reported the Pd-catalyzed formation of 2-(2-oxoethyl)oxiranes **9** from α-halo ketones **8** *via* carbonyl addition of tin enolate **1** in THF reflux.[6] The milder conditions are required in order to prevent the transformation of the product 2-(2-oxoethyl)oxiranes into furan derivatives. We have previously reported the formation of 1,4-diketones **10** under mild conditions by the coordination procedure of tin enolates, in which the generation of small amounts of oxirane was assumed to be responsible for the catalysis of the complex of Bu_3SnBr and the ligands.[7b] The by-product Bu_3SnBr arising from destannylbromination increases in progress with the formation of 1,4-diketones. The coordination of the ligands to the resulting Bu_3SnBr leads to the lack of high-coordinate tin enolates. This is the reason why excess amounts of ligands like HMPA and Bu_4NBr are indispensable for predominant formation of 1,4-diketones.



Scheme 6

For the selective formation of oxiranes under mild conditions, we made further investigation into numerous tin complex catalysts and Ph_4SbBr. The catalytic effects in the reaction of tin enolate **1** with 2-bromo-1-phenylethanone (**8a**) are summarized in Table 4. The use of Bu_3SnBr-onium salts as catalysts caused the selective formation of oxirane **9aa** by the carbonyl addition at room temperature for 2 h (entries 2, 3, and 4), although noncatalyzed reaction resulted in low conversion (entry 1). The low yields by using Bu_3SnBr-Et_4NBr or -Me_4NBr were perhaps due to their low solubility in reaction mixture (entries 5, 6). The use of phosphine oxides, HMPA or Bu_3PO, as ligands gave high yields (entries 7, 8) in spite of requiring longer reaction times. The addition of only

Bu_3SnBr did not promote the oxirane-formation at all in similar to the noncatalyzed run (entry 10). Even without Bu_3SnBr, a catalytic amount of Ph_4SbBr promoted selective formation of **9aa** (entry 12).

Table 4. Effect of Catalysts in the Reaction of Tin Enolate **1** with 2-bromo-1-phenylethanone (**8a**)[a)]

Entry	Tin enolate	Catalyst	Time/h	Yield/%			
					9	**10**	
1	**1a**	none	2	**aa:**	3	3	18[b)]
2		Bu_3SnBr-Bu_4NBr	2		66	14	
3		Bu_3SnBr-Bu_4PBr	2		63	12	
4		Bu_3SnBr-Ph_4SbBr	2		95	5	
5		Bu_3SnBr-Et_4NBr	2		29	4	
6		Bu_3SnBr-Me_4NBr	21		28	4	
7		Bu_3SnBr-HMPA	21		65	15	
8		Bu_3SnBr-Bu_3PO	21		61	13	
9		Bu_2SnBr_2-Bu_4NBr	2		49	7	
10		Bu_3SnBr	7		0	0	23[b)]
11		Bu_4NBr	3		44	18	
12		Ph_4SbBr	3		78	5	
13[c)]		Bu_4NBr	2		14	43	
14[c)]		Bu_4PBr	3		16	34	
15[c)]		Ph_4SbBr	2		71	8	
16	**1b**	Ph_4SbBr	3	**ba:**	73	11	
17	**1d**	Ph_4SbBr	4	**da:**	36	30	
18		Bu_3SnBr-Bu_4NBr	3		38	5	

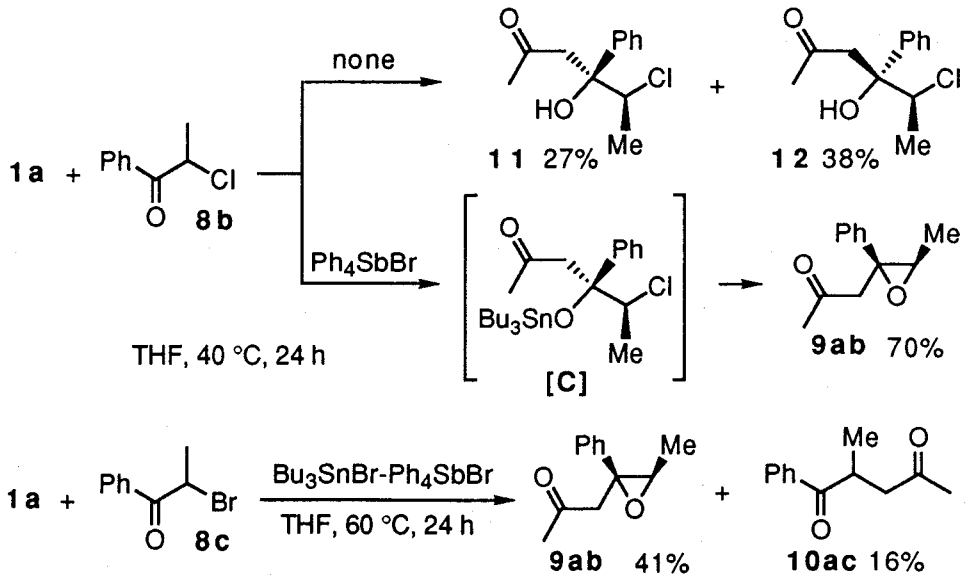
a) Tin enolate **1** (1.2 mmol), **8a** (1.0 mmol), catalyst (0.1 mmol), THF (1 mL), 25 °C.
b) The adduct product 5-Bromo-4-hydroxy-4-phenyl-2-pentanone derived *via* carbonyl attack was obtained.[7b)]
c) Onium halide (1.8 mmol) was used.

Also in the reaction of **1** with **8**, Ph_4SbBr and five-coordinate organotin bromide showed the similar and effective catalytic activities under the conditions milder than those of Pd-catalyst reaction.[6]

The addition of an equimolar amount of onium salt afforded interesting results

(entries 13, 14, and 15). The high-coordinate tin enolates were generated by coordination of the bromide anion from Bu_4NBr or Bu_4PBr because of their ionic N-Br or P-Br bonds, giving 1,4-diketone **10aa** in halide substitution.[5,7] On the contrary, 2-(2-oxoethyl)oxirane **9aa** was formed selectively even in the presence of equimolar amount of Ph_4SbBr. No significant coordination to tin enolate would occur owing to low-ionic character of Sb-Br bond[17] although no NMR study for the mixture of tin enolate **1a** with Ph_4SbBr could not be carried out because of the poor solubility.

A stereoselective addition to carbonyl carbon was found in the reaction with acyclic secondary α-halo ketones **8b** or **8c** in Scheme 7. The Ph_4SbBr-catalyzed reaction of **1a** with 2-chloro-1-phenyl-1-propanone (**8b**) proceeded at 40 °C to give the oxirane **9ab** in 70% yield as a single isomer bearing *cis*-conformation for Ph and Me groups, while no stereoselective addition was observed without the catalyst to give a mixture of chlorohydrin derivatives (**11/12** = 42/58). The reaction with 2-bromo-1-phenyl-1-propanone (**8c**) gave the oxirane **9ab** in 41% yield along with 1,4-diketone **10ac** in the presence of Bu_3SnBr-Ph_4SbBr. In contrast, noncatalyzed oxirane formation from **1a** and **8c** required heating at 80 °C in benzene and showed low selectivity.[7]



Scheme 7

In these reactions the formation of Cram products was enhanced by the coordination of Ph_4SbBr to the carbonyl group. It is noteworthy that in the case of these α-chloro ketones, no oxirane was produced in the absence of catalysts, only chlorohydrin derivatives being obtained. This result strongly indicated that these catalysts promoted a destannylhalogenation although the formation of a stable complex between Ph_4SbBr and Bu_3SnBr was not detected in the aforementioned NMR study. Details are not clear, but we tentatively assume that a weak interaction between Ph_4SbBr and Bu_3SnBr acts an important role in the elimination of Bu_3SnBr to yield oxiranes catalytically.

These catalytic reactions proceeded at lower temperature than in Pd-catalyst system, therefore the 2-(2-oxoethyl)oxiranes formed could be hardly rearranged to furane derivatives.[6]

In conclusion, both five-coordinate organotin bromide complexes and tetraphenylstibonium bromide which have the similar structures, trigonal bipyramid, including axial metal-Br bonds showed the analogous catalytic activities. These catalytic systems could be treated under milder conditions than those of Pd-catalyst, and induced the chemo- and stereoselective addition to α-halo ketone at the carbonyl group efficiently. They are convenient and useful catalysts for stereoselective synthesis of oxiranes.

3-4 Experimental Section

General. Melting points were taken on a Yanagimoto melting point apparatus and are uncorrected. IR spectra (KRS-5 windows or KBr pellets) were recorded on a Hitachi 260-30 spectrophotometer. ^1H and ^{13}C NMR spectra were obtained with a Hitachi R-90H (90 and 22.6 MHz) or a JEOL JNM-GSX-400 (400 and 100 MHz) spectrometer, respectively with TMS as internal standard. ^{119}Sn NMR spectra were obtained with a JEOL JNM-GSX-400 (149 MHz) spectrometer with Me_4Sn as internal standard. Mass spectra were recorded on a JEOL JMS-DS303 or a Shimadzu GCMS-QP2000A spectrometer. GLC analyses were performed on a Shimadzu GC-8A with FID using a 2

m × 3 mm column packed with SE-52. Flash chromatography was performed on silica gel (Wakogel C-300). Bulb-to-bulb distillation (Kugelrohr) was accomplished in a Sibata GTO-250RS at the oven temperature and pressure indicated. Yields were determined by GLC or ^{1}H NMR using internal standards.

Materials. THF was distilled from sodium and benzophenone. HMPA was distilled from CaH_2. The onium salts, Bu_4NBr, Bu_4PBr, Me_4NBr, and Et_4NBr were commercial products and dried *in vacuo* before using. Tetraphenylstibonium bromide (Ph_4SbBr) was prepared from commercial Ph_3Sb, $AlCl_3$, and PhBr as the method reported in the literature.[9] Tin enolates **1a-d** were prepared by known methods.[4] 2-Chlorocyclohexanone (**2a**), 2-bromo-1-phenylethanone (**8a**) and 2-bromo-1-phenyl-1-propanone (**8c**) were commercial products. 2-Chloro-2-methylcyclohexanone (**2b**) and 2-chloro-1-phenyl-1-propanone (**8b**) were prepared according to described methods.[19] The compounds **5a** and **5b**, *cis*- and *trans*-2-chloro-4-*tert*-butylcyclohexanone, were prepared by standard procedure.[20]

General Procedure for Synthesis of Chlorohydrins 3 and 4. 2-Chlorocyclohexanone **2** (3.0 mmol) was added to a stirred solution of a tin enolate **1** (6.0 mmol) and catalyst (0.3 mmol) in dry THF (3 mL) and the mixture was stirred at 40 °C for 24 h. Diethyl ether (100 mL) and aqueous NH_4F (15%; 40 mL) were added, the organic layer was separated and washed with water (50 mL × 2), dried ($MgSO_4$) and evaporated. The crude product was purified by flash chromatography on silica gel and/or distillation to give the chlorohydrin **3**. In the noncatalyzed reaction, chlorohydrin **4** was obtained as above method.

1-Acetonyl-*c*-2-chlorocyclohexan-*r*-1-ol (3aa): Obtained from **1a** and **2a** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 5:1) and distillation: bp 100 °C/1.5 mmHg; IR (neat) 3450 (OH) and 1700 (C=O) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 4.05 (1H, dd, J = 11.5 and 4.6 Hz, 2-H), 3.27 (1H, s, OH), 2.95, 2.64 (each 1H, each d, each J = 16.6 Hz, CH_2C=O), 2.21 (3H, s, CH_3), 2.15-1.2 (8H, m); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ = 208.8 (s, C=O), 72.5 (s, C-

1), 67.8 (d, C-2), 51.7 (t, $\underline{C}H_2C=O$), 36.1 (t), 32.1 (t), 32.0 (q, Me), 25.6 (t), 20.4 (t); MS *m/z* 192 ($M^+ + 2$), 190 (M^+); Found: *m/z* 190.0735. Calcd for $C_9H_{15}ClO_2$: M, 190.0762. Found: C, 56.46; H, 8.01; Cl, 18.29%. Calcd for $C_9H_{15}ClO_2$: C, 56.69; H, 7.93; Cl, 18.59%.

1-Acetonyl-*t*-2-chlorocyclohexan-*r*-1-ol (4aa): Obtained from **1a** and **2a** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 10:1): IR (neat) 3450 (OH) and 1690 (C=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 4.26 (1H, d, *J* = 1.3 Hz, OH), 4.13 (1H, t, *J* = 3.8 Hz, 2-H), 3.07, 2.54 (each 1H, each d, each *J* = 17.6 Hz, $CH_2C=O$), 2.22 (3H, s, CH_3), 2.35-2.20 (1H, m), 1.8-1.4 (7H, m); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ = 211.0 (s, C=O), 73.0 (s, C-1), 63.9 (d, C-2), 48.9 (t, $\underline{C}H_2C=O$), 32.9 (t), 31.8 (q, Me), 30.1 (t), 20.7 (t), 20.3 (t); MS *m/z* 192 ($M^+ + 2$), 190 (M^+); Found: *m/z* 190.0728. Calcd for $C_9H_{15}ClO_2$: M, 190.0762.

***c*-2-Chloro-1-phenacylcyclohexan-*r*-1-ol ():** Obtained from **1b** and **2a** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 20:1) and distillation: bp 123 °C/0.7 mmHg; IR (neat) 3450 (OH) and 1670 (C=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 7.88-7.85 (2H, m), 7.51-7.35 (3H, m), 4.11 (1H, dd, *J* = 11.7 and 4.4 Hz, 2-H), 3.52 (1H, s, OH), 3.38, 3.13 (each 1H, each d, each *J* = 16.6 Hz, $CH_2C=O$), 2.1-1.2 (8H, m); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ = 200.0 (s, C=O), 137.1 (s), 133.2 (d), 128.3 (d), 127.8 (d), 72.9 (s, COH), 67.7 (d, CCl), 46.3 (t, $\underline{C}H_2C=O$), 36.3 (t), 32.1 (t), 25.7 (t), 20.3 (t); MS *m/z* 254 ($M^+ + 2$), 252 (M^+); Found: *m/z* 252.0908. Calcd for $C_{14}H_{17}ClO_2$: M, 252.0918.

***t*-2-Chloro-1-phenacylcyclohexan-*r*-1-ol (4ba):** Obtained from **1b** and **2a** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 20:1): mp 71-72 °C; IR (neat) 3480 (OH) and 1665 (C=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 7.99-7.96 (2H, m), 7.62-7.46 (3H, m), 4.64 (1H, s, OH), 4.26 (1H, t, *J* = 3.30 Hz, 2-H), 3.63, 3.01 (each 1H, each d, each *J* = 17.6 Hz, $CH_2C=O$), 2.37-2.29 (1H, m) 1.94-1.47 (7H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 202.2 (-, C=O), 137.0, 133.8 (+), 128.7 (+), 128.2 (+), 73.5 (-, C-1), 63.9 (+, C-2), 44.0 (-,

$\underline{C}H_2C{=}O$), 33.1 (-), 30.1 (-), 20.7 (-), 20.2 (-); MS *m/z* 254 ($M^+ + 2$), 252 (M^+); Found: *m/z* 252.0900. Calcd for $C_{14}H_{17}ClO_2$: M, 252.0918.

***c*-2-Chloro-1-(3,3-dimethyl-2-oxobutyl)cyclohexan-*r*-1-ol (3ca):** Obtained from **1c** and **2a** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 60:1); IR (neat) 3400 (OH) and 1690 (C=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 4.07 (1H, dd, *J* = 11.7 and 4.4 Hz, 2-H), 3.83 (1H, s, OH), 2.94, 2.71 (each 1H, each d, each*J* = 17.6 Hz, $CH_2C{=}O$), 2.1-1.2 (8H, m), 1.14 (9H, s, *t*-Bu); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 217.4 (s, C=O), 72.8 (s, C-1), 67.7 (d, C-2), 45.0 (s, $\underline{C}Me_3$), 44.7 (t, $\underline{C}H_2C{=}O$), 36.3 (t), 32.1 (t), 26.2 (q, $C\underline{Me_3}$), 20.4 (t), 20.4 (t); MS *m/z* 232 (M^+), 197 (M^+ - Cl); Found: *m/z* 232.1237. Calcd for $C_{12}H_{21}ClO_2$: M, 232.1231.

***t*-2-Chloro-1-(3,3-dimethyl-2-oxobutyl)cyclohexan-*r*-1-ol (4ca):** Obtained from **1c** and **2a** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 60:1); IR (neat) 3430 (OH) and 1675 (C=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 4.72 (1H, s, OH), 4.17 (1H, t, *J* = 3.42 Hz, 2-H), 3.13, 2.48 (each 1H, each d, each *J* = 18.1 Hz, $CH_2C{=}O$), 2.32-2.29 (1H, m), 1.8-1.4 (7H, m), 1.16 (9H, s, *t*-Bu); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 219.3 (s, C=O), 73.0 (s, C-1), 63.4 (d, C-2), 45.0 (s, $\underline{C}Me_3$), 42.8 (t, $\underline{C}H_2C{=}O$), 32.8 (t), 29.9 (t), 26.2 (q, $C\underline{Me_3}$), 20.6 (t), 20.0 (t); MS *m/z* 234 ($M^+ + 2$), 232 (M^+), 197 (M^+ - Cl); Found: *m/z* 232.1242. Calcd for $C_{12}H_{21}ClO_2$: M, 232.1231.

1-Acetonyl-*c*-2-chloro-2-methylcyclohexan-*r*-1-ol (3ab): Obtained from **1a** and **2b** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 10:1) and distillation: bp 75 °C/0.7 mmHg; IR (neat) 1720 (C=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 2.86, 2.61 (each 1H, each d, each *J* = 17.1 Hz, $CH_2C{=}O$), 2.18 (3H, s, $CH_3C{=}O$), 2.96-1.25 (8H, m), 1.26 (3H, s, 2-CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ = 206.0 (s, C=O), 62.1 (s), 61.7 (s), 49.8 (t, $\underline{C}H_2C{=}O$), 31.3 (t), 30.4 (q, MeC=O), 29.9 (t), 20.7 (t), 20.5 (q, 2-Me), 25.3 (t); MS *m/z* 207 (M^+ + 3), 205 ($M^+ + 1$), 169 (M^+ - Cl); Found: *m/z* 205.0985. Calcd for $C_{10}H_{18}ClO_2$: M+1,

205.0996.

1-Acetonyl-*t*-2-chloro-2-methylcyclohexan-*r*-1-ol (4ab): Obtained from **1a** and **2b** according to the general procedure by flash chromatography (eluted by hexane-diethyl ether, 10:1) and distillation: bp 90 °C/0.7 mmHg; IR (neat) 1710 (C=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 3.36 (1H, s, OH), 2.94, 2.47 (each 1H, each d, each *J* = 15.1 Hz, $\underline{C}H_2C{=}O$), 2.18 (3H, s, $CH_3{=}O$), 1.9-1.2 (8H, m), 1.56 (3H, s, 2-CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ 209.6 (s, C=O), 80.1 (s), 75.2 (s), 47.9 (t, $\underline{C}H_2C{=}O$), 39.1 (t), 33.7 (t), 32.5 (q, MeC=O), 26.3 (q, 2-Me), 23.0 (t), 21.0 (t); MS *m/z* 207 (M^+ + 3), 205 (M^+ + 1), 169 (M^+ - Cl); Found: *m/z* 205.1004. Calcd for $C_{10}H_{18}ClO_2$: M+1, 205.0996.

1-Acetonyl-*c*-4-*tert*-butyl-*c*-2-chlorocyclohexan-*r*-1-ol (6a): Obtained from **1a** and *cis*-4-*tert*-butyl-2-chlorocyclohexanone (**5a**) in THF at 40 °C for 24 h and purified by flash chromatography (eluted by hexane-diethyl ether, 3:2); mp 56-58 °C; IR (neat) 3480 (OH) and 1690 (C=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 4.06 (1H, dd, *J* = 12.2 and 4.4 Hz, 2-H), 3.25 (1H, s, OH), 2.98, 2.61 (each 1H, each d, each *J* = 16.6 Hz, $CH_2C{=}O$), 2.20 (3H, s, $CH_3C{=}O$), 2.1-1.75 (3H, m), 1.55-1.4 (3H, m), 1.25-1.05 (1H, m), 0.87 (9H, s, *t*-Bu); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ = 208.8 (-, C=O), 72.0 (-, C-1), 68.7 (+, C-2), 51.9 (-, $\underline{C}H_2C{=}O$), 48.3 (+, C-4), 36.1 (-), 33.4 (-), 32.4 (-, $\underline{C}Me_3$), 32.0 (+, $\underline{C}H_3C{=}O$), 27.4 (+, $C\underline{Me}_3$), 21.2 (-); MS *m/z* 248 (M^+ + 2), 246 (M^+); Found: C, 63.10; H, 9.36; Cl, 14.46%. Calcd for $C_{13}H_{23}ClO_2$: C, 63.27; H, 9.39; Cl, 14.37%. The stereochemistry of the title compound **6a** which has a fixed conformation was established by ^1H NMR spectroscopy. When the proton at δ 4.06 (2-H) was irradiated, NOEs with the methylene protons (δ 2.98, d) and (δ 2.61, d) were observed.

1-Acetonyl-*c*-4-*tert*-butyl-*t*-2-chlorocyclohexan-*r*-1-ol (6b): Obtained from **1a** and **5b** under the condition noted in Table 2 and purified by flash chromatography (eluted by hexane-diethyl ether, 10:1); bp 80 °C/0.08 mmHg; IR (neat) 3480 (OH) and 1708 (C=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 4.27 (1H, t, *J* = 2.4

Hz, 2-H), 4.21 (1H, d, J = 1.5 Hz, OH), 3.09, 2.49 (each 1H, each d, each J = 18.1 Hz, CH_2C=O), 2.22 (3H, s, CH_3C=O), 2.1-1.4 (7H, m), 0.86 (9H, s, t-Bu); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ = 211.4 (-, C=O), 72.4 (-, C-1), 63.4 (+, C-2), 50.3 (-, $\underline{C}H_2C$=O), 40.0 (+, C-4), 32.3 (-), 31.8 (-, $\underline{C}Me_3$), 31.6 (+, $\underline{C}H_3C$=O), 30.4 (-), 27.4 (+, $C\underline{Me}_3$), 21.2 (-); MS m/z 248 (M^+ + 2), 246 (M^+); Found: m/z 246.1371. Calcd for $C_9H_{15}ClO_2$: M, 246.1388.

1-Acetonyl-*t*-4-*tert*-butyl-*c*-2-chlorocyclohexan-*r*-1-ol (7b): Obtained from **1a** and **5b** under the catalyzed condition noted in Table 2 and purified by flash chromatography (eluted by hexane-diethyl ether, 10:1); IR (neat) 3480 (OH) and 1710 (C=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 4.50 (1H, br s, 2-H), 2.98 (1H, s, OH), 2.77, 2.66 (each 1H, each d, each J = 14.2 Hz, CH_2C=O), 2.26 (3H, s, CH_3C=O), 2.1-2.0 (1H, m), 1.9-1.8 (1H, m), 1.75-1.65 (4H, m), 1.2-1.0 (1H, m), 0.87 (9H, s, t-Bu); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ = 208.6 (-, C=O), 72.5 (-, C-1), 68.3 (+, C-2), 48.2 (-, $\underline{C}H_2C$=O), 39.7 (+, C-4), 33.4 (-), 32.8 (+, $\underline{C}H_3C$=O), 32.3 (-), 31.7 (-, $\underline{C}Me_3$), 27.5 (+, $C\underline{Me}_3$), 23.7 (-); MS m/z 248 (M^+ + 2), 246 (M^+); Found: m/z 246.1394. Calcd for $C_{13}H_{23}ClO_2$: M, 246.1388.

Determination of Stereochemistry. Stereochemistries of **3** and **4** were determined as follows. The ^1H and ^{13}C NMR spectra of **3aa** and **4aa** were in good analogy with 1-acetonyl-*c*-4-*tert*-butyl-*c*-2-chlorocyclohexan-*r*-1-ol (**6a**)[8] and 1-acetonyl-*c*-4-*tert*-butyl-*t*-2-chlorocyclohexan-*r*-1-ol (**6b**), respectively. The other chlorohydrins **3** and **4** showed analogous peaks of NMR spectra of **3aa** and **4aa**, respectively.

Synthesis of 2-(2-Oxoethyl)oxirane (9). Typical procedure for synthesis of **9aa** catalyzed by Bu_3SnBr-Bu_4NBr complex. — A mixture of tributyltin bromide (0.1 mmol) and tetrabutylammonium bromide (0.1 mmol) in THF (1 mL) was stirred for 20 min and tin enolate **1a** (1.2 mmol) and 2-bromo-1-phenylethanone (**8a**) (1.0 mmol) were added, then stirred for 2 h under nitrogen.

The spectral data of compounds **9aa**, **9ba**, **9da** , **9ab**, **10aa**, **10ba**, **10da** and **10ac** were described in our previous papers.[5,7b]

Noncatalyzed Reaction of 1a with 8b. 2-Chloro-1-phenyl-1-propanone (**8b**) (5.0 mmol) was added to a stirred solution of a tin enolate **1a** (10.0 mmol) in dry THF (6 mL) and the mixture was stirred at 40 °C for 24 h. Diethyl ether (100 mL) and aqueous NH_4F (15%; 40 mL) were added, the organic layer was separated and washed with water (50 mL × 2), dried ($MgSO_4$) and evaporated. The crude product was purified by flash chromatography on silica gel (eluted by hexane-diethyl ether, 5:1) to give **11** and **12** in this order. Stereochemistries of these compounds **11** and **12** were determined by cyclization of the intermediate carbonyl adduct as follows. After stirring the mixture of **8b** (1.0 mmol) and **1a** (2.0 mmol) in THF (2 mL) at 40 °C for 24 h, 2.0 mmol of HMPA was added and the solution was stirred at 40 °C for 3 h. After work-up, cyclized product **9ab** (18%) from [C], non-cyclized **12** (32%), and **11** (6%) were obtained. The structure of **9ab** was identified in comparison with the sample obtained previously.[7b]

(4*R,5*R**)-5-Chloro-4-hydroxy-4-phenylhexan-2-one (11):** IR (neat) 3425 (OH) and 1700 (C=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 7.55-7.25 (5H, m), 4.79 (1H, s, OH), 4.27 (1H, q, *J* = 6.67 Hz, 5-H), 3.38, 3.22 (each 1H, each d, each *J* = 17.1 Hz, 3-H_2), 2.18 (3H, s, 1-H_3), 1.29 (3H, d, *J* = 6.67 Hz, 6-H_3); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ = 210.1 (s, C-2), 141.1 (s), 127.7 (d), 127.4 (d), 126.0 (d), 77.2 (s, C-4), 63.6 (d, C-5), 48.7 (t, C-3), 31.7 (q, C-1), 19.3 (q, C-6); MS *m/z* 229 (M^+ + 3), 227 (M^+ + 1); Found: C, 63.42; H, 6.88; Cl, 15.52%. Calcd for $C_{12}H_{15}ClO_2$: C, 63.58; H, 6.67; Cl, 15.64%.

(4*S,5*R**)-5-Chloro-4-hydroxy-4-phenylhexan-2-one (12):** IR (neat) 3450 (OH) and 1700 (C=O) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 7.42-7.25 (5H, m), 4.73 (1H, s, OH), 4.19 (1H, q, *J* = 6.67 Hz, 5-H), 3.28 (2H, s), 2.04 (3H, s, 1-H_3), 1.27 (3H, d, *J* = 6.67 Hz, 6-H_3); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ = 209.7 (s, C-2), 142.9 (s), 128.4 (d), 127.5 (d), 125.4 (d), 77.6 (s, C-4), 65.7 (d, C-5), 51.1 (t, C-3), 32.0 (q, C-1), 18.9 (q, C-6); MS *m/z* 229 (M^+ + 3), 227 (M^+ + 1); Found: C, 63.18; H, 6.68; Cl, 15.78%. Calcd for $C_{12}H_{15}ClO_2$: C, 63.58; H, 6.67; Cl, 15.64%.

3-5 References and Notes

1. M. Pereyre, J.-P. Quintard, and A. Rahm, *Tin in Organic Synthesis*, Butterworth, London, 1987;
2. I. Shibata and A. Baba, *Org. Prep. Proced. Int.*, **26**, 85 (1994).
3. (a) J. G. Noltes, H. M. J. C. Creemers, and G. J. M. Van Der Kerk, *J. Organomet. Chem.*, **11**, 21 (1968); (b) S. S. Labadie, and J. K. Stille, *Tetrahedron*, **40**, 2329 (1984); (c) Y. Yamamoto, H. Yatagi, and K. Maruyama, *J. Chem. Soc., Chem. Commun.*, **1981**, 162.
4. (a) M. Pereyre, B. Bellegarde, J. Mendelsohn, and J. Valade, *J. Organomet. Chem.*, **11**, 97 (1968); (b) K. Kobayashi, M. Kawanisi, T. Hitomi, and S. Kozima, *Chem. Lett.*, **1984**, 497.
5. M. Yasuda, Y. Katoh, I. Shibata, A. Baba, H. Matsuda, and N. Sonoda, *J. Org. Chem.*, **59**, 4386 (1994).
6. I. Pri-Bar, P. S. Pearlman, and J. K. Stille, *J. Org. Chem.*, **48**, 4629 (1983).
7. (a) A. Baba, M. Yasuda, K. Yano, I. Shibata, and H. Matsuda, *J. Chem. Soc., Perkin Trans. 1*, **1990**, 3205; (b) M. Yasuda, T. Oh-hata, I. Shibata, A. Baba, and H. Matsuda, *J. Chem. Soc., Perkin Trans. 1*, **1993**, 859.
8. M. Yasuda, T. Oh-hata, I. Shibata, A. Baba, H. Matsuda, and N. Sonoda, *Tetrahedron Lett.*, **35**, 8627 (1994).
9. Tetraphenylstibonium bromide is stable and easy to handle. It was prepared according to the described method: J. Chatt, and F. G. Mann, *J. Chem. Soc.*, **1940**, 1195.
10. (a) A. Baba, T. Nozaki, and H. Matsuda, *Bull. Chem. Soc. Jpn.*, **60**, 1552 (1987); (b) A. Baba, T. Nozaki, and H. Matsuda, *Nippon Kagaku Kaishi*, **1987**, 1189.
11. (a) A. Baba, H. Kashiwagi, and H. Matsuda, *Organometallics*, **6**, 137 (1987); (b) M. Fujiwara, A. Baba, and H. Matsuda, *J. Heterocyclic Chem.*, **26**, 1659 (1989).
12. (a) A. Baba, M. Fujiwara, and H. Matsuda, *Tetrahedron Lett.*, **27**, 77 (1986); (b)

M. Fujiwara, A. Baba, and H. Matsuda, *Bull. Chem. Soc. Jpn.*, **63**, 1069 (1990).

13. K. Yano, N. Amishiro, A. Baba, and H. Matsuda, *Bull. Chem. Soc. Jpn.*, **64**, 2661 (1991).
14. (a) E. C. Ashby, and J. T. Laemmle, *Chem. Rev.*, **75**, 521 (1975); (b) Y. Senda, S. Nakano, H. Kunii, and H. Itoh, *J. Chem. Soc., Perkin Trans. 2*, **1993**, 1009.
15. E. A. Basso, C. Kaiser, R. Rittner, and J. B. Lambert, *J. Org. Chem.*, **58**, 7865 (1993).
16. (a) J. Holecek, M. Nadvornik, and K. Handlir, *J. Organomet. Chem.*, **241**, 177 (1983); (b) M. Nadvornik, J. Holecek, and K. Handlir, *J. Organomet. Chem.*, **275**, 43 (1984).
17. (a) J. N. R. Ruddick, D. Sams, and J. C. Scott, *Inorg. Chem.*, **13**, 1503 (1974); (b) G. G. Long, J. G. Stevens, R. J. Tullbane, and L. H. Bowen, *J. Am. Chem. Soc.*, **92**, 4230 (1970).
18. K. Maruoka, T. Itoh, M. Sakurai, K. Nonoshita, and H. Yamamoto, *J. Am. Chem. Soc.*, **110**, 3588 (1988).
19. G. A. Olar, L. Ohannesian, M. Arvanaghi, and G. K. S. Parakash, *J. Org. Chem.*, **49**, 2032 (1984).
20. N. L. Allinger, J. Allinger, L. A. Freiberg, R. F. Czaja, and N. A. Lebel, *J. Am. Chem. Soc.*, **82**, 5876 (1960).

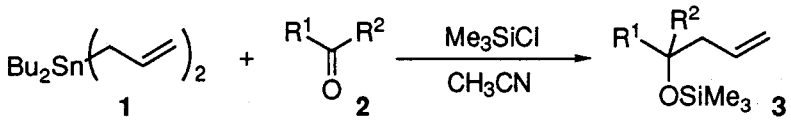
Chapter 4

Chlorotrimethylsilane-Acetonitrile System as a New Promoter for Carbonyl Allylation by Diallyldibutyltin

4-1 Introduction

The addition of allylic tins to carbonyl compounds is a potentially useful tool for stereocontrolled carbon-carbon bond formation, when carbonyl moieties are generally activated by metallic Lewis acids like $TiCl_4$ and BF_3, but transmetallations of allylic tins are often accompanied.[1-3] Therefore, the reaction conditions such as addition orders of reagents must be controlled carefully. The development of new activation method is still a significant target. Chlorotrimethylsilane has recently received attention as a mild and unique activator in Michael type addition using such metallic reagents as cuprates,[4] zincates,[5] silyl enolates[6] and tin (II) enolates.[7]

We now report an alternative promising system in which a good enhancement of the allylation by diallyldibutyltin was obtained with chlorotrimethylsilane in acetonitrile.



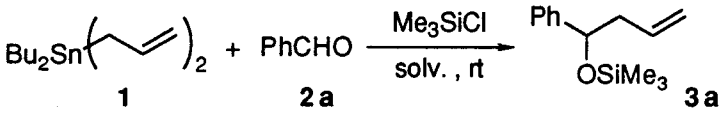
Of particular note is the sufficient use of an equimolar amount of acetonitrile to chlorotrimethylsilane. In addition, the isolation procedure of the produced silyl ethers is often tedious under considerably acidic conditions, where careful work-up using an amine at low temperature is required for preventing desilylation.[8] On the contrary, our procedure required only simple treatment washing with NH_4F aq to obtain the silylating product without desilylation.

4-2 Allylation by Diallyldibutyltin in Me_3SiCl-CH_3CN System

Table 1 shows the effect of solvents examined for the reaction of diallyldibutyltin

(**1**) with benzaldehyde (**2a**) in the presence of Me_3SiCl.[9] The choice of solvents was definitively important. The use of benzene completely depressed the allylation. Either THF or dichloromethane, representative solvents for Lewis acid-promoted allylation, gave **3a** in only 5% and 8% yields, respectively, and the allylic tin remained unreactive. Among many solvents examined the most effective one was acetonitrile, affording the silylating product **3a** quantitatively in a short time at ambient temperature. Even adding equimolar acetonitrile in THF solution dramatically accelerated the allylation (Entry 7). Using an equimolar amount of benzonitrile also caused effective carbonyl addition though silylation was insufficient (Entry 8). The addition of either HMPA or LiCl depressed the yield of **3a** (entries 9 and 10).[9]

Table 1. Solvent Effect in the Reaction of Diallyldibutyltin (**1**) with Benzaldehyde (**2a**)[a]



1 **2a** **3a**

Entry	Solv.	Time /h	Yield /%
1	benzene	5	trace
2	THF	1	5
3	dichloromethane	2	8
4	1,2-dichloroethane	1	trace
5	CH_3CH_2CN	1	95
6	CH_3CN	1	>99
7	THF (CH_3CN[b])	1.5	83
8	THF (PhCN[b])	1	53(35)[c]
9	CH_3CN (HMPA[b])	1	40
10	CH_3CN (LiCl[b])	1	75

[a] All reactions were carried out in solvent (2 mL) using allyltin **1** (1 mmol), aldehyde **2a** (2 mmol) and Me_3SiCl (2 mmol) at room temperature.
[b] 2 mmol. [c] Corresponding homoallylalcohol was obtained.

The formation of a complex between iodotrimethylsilane and acetonitrile has been reported by Olah and coworkers.[10] These facts suggest that an appropriate interaction between chlorotrimethylsilane and acetonitrile is crucial for the allylation, and HMPA

perhaps disturbed the interaction. This is in an interesting contrast to the effective support of Me_3SiCl-HMPA system in 1,4-addition of organocuprates to enones, where effective silylation has been reported.[4b,11]

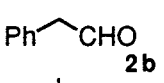
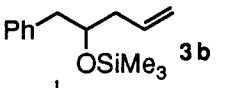
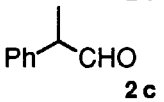
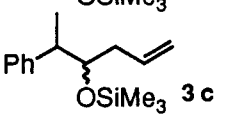
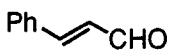
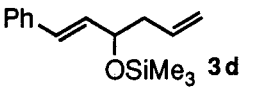
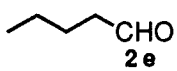
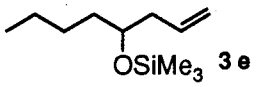
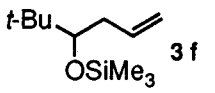
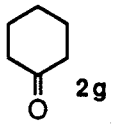
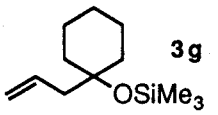
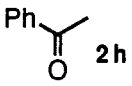
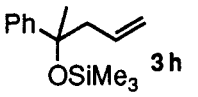
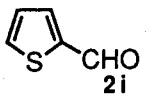
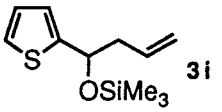
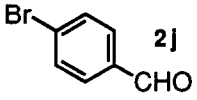
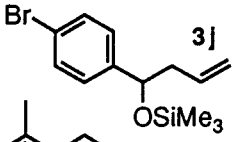
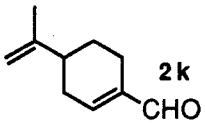
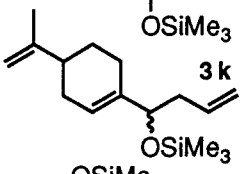
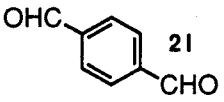
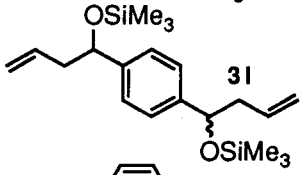
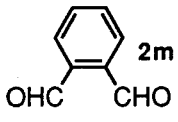
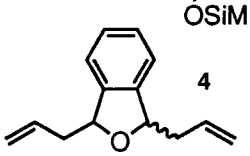
No reaction of diallyldimethylsilane with benzaldehyde in the presence of Me_3SiCl took place at room temperature.

Allylation of various carbonyl compounds was investigated and the results are shown in Table 2. It is noteworthy that both of the two allyl groups of **1** participated in this allylation reaction. Acetonitrile could be conveniently used as solvent although an equimolar addition of acetonitrile in THF effected the allylation (**2b**, **e**, **g**, and **h**). Almost all the reactions with aldehydes proceeded exothermically and completed within 1 h. The reaction with branched aldehyde **2c** proceeded to form corresponding homoallyl silyl ether in a high yield. Only 1,2-adduct **3d** was obtained in the reaction with α,β-unsaturated aldehyde **2d**. The aldehyde bearing a bulky substituent **2f** gave a moderate yield. The cyclic ketone **2g** afforded **3g** in high yield, although acetophenone (**2h**) gave a low yield even after a prolonged reaction period at 55 °C. The functional groups in the aldehydes **2i, 2j, 2k** tolerated the carbonyl allylation. Both the carbonyl groups of terephthalaldehyde (**2l**) were allylated to produce the corresponding homoallyl silyl ether **3l**. The phthalan derivative **4** from **2m** seemed to be produced *via* trimethylsilylation because no formation of **4** was detected in the absence of chlorotrimethylsilane.

As to the mechanistic aspect, chlorotrimethylsilane combined with acetonitrile[11] may coordinates the carbonyl oxygen or promote the silylation of the resulting homoallyl stannyl ether into the silyl ether **3**. Although no confirmed evidence has been obtained, the activation of carbonyl moieties seems to be a significant step because no addition to aldehydes was detected in the absence of Me_3SiCl.[12] A possibility of the interaction between acetonitrile and tin reagent can not be excluded in this stage.

The combination of chlorotrimethylsilane and acetonitrile is now a new promoter for carbonyl allylation by diallyldibutyltin and a new approach in the syntheses of homoallyl silyl ethers.

Table 2. Allylation of Carbonyl Compounds[a]

Entry	Carbonyl	Product[b]	Yield /%
1	 **2b**	 **3b**	>99 >99[c]
2	 **2c**	 **3c**	>99 (68/32)[d]
3	 **2d**	 **3d**	91
4	 **2e**	 **3e**	72, 81[c]
5	*t*-BuCHO **2f**	 **3f**	63
6[e]	 **2g**	 **3g**	90, 61[c]
7[f]	 **2h**	 **3h**	32, 57[c]
8	 **2i**	 **3i**	95
9	 **2j**	 **3j**	84
10	 **2k**	 **3k**	47 (50/50)[d] 92[g](50/50)[d]
11[h]	 **2l**	 **3l**	72 (50/50)[d]
12[h]	 **2m**	 **4**	97 (77/23)[i]

[a] Unless otherwise noted, reactions were carried out in CH_3CN (2 mL) using allyltin **1** (1 mmol), carbonyl **2** (2 mmol) and Me_3SiCl (2 mmol) at room temperature for 1 h. [b] All compounds showed characteristic spectral data and exact mass spectroscopic data. [c] CH_3CN (2 mmol), THF (2 mL). [d] Ratio of diastereomers determined by GLC. [e] 24 h. [f] 55 °C, 30 h. [g] 6 h. [h] Allyltin **1**, 2 mmol. [i] Ratio of diastereomers was obtained after column chromatography by GLC.

4-3 Experimental Section

General. Melting points were taken on a Yanagimoto melting point apparatus and are uncorrected. IR spectra were recorded on a Hitachi 260-30 spectrophotometer. ^{1}H and ^{13}C NMR spectra were obtained with a Hitachi R-90H (90 and 400 MHz) or a JEOL JNM-GSX-400 (400 and 100 MHz) spectrometer, respectively with TMS as internal standard. Mass spectra were recorded on a JEOL JMS-DS303 or a Shimadzu GCMS-QP2000A spectrometer. GLC analyses were performed on a Shimadzu GC-8A with FID using a 2 m × 3 mm column packed with SE-52. Bulb-to-bulb distillation (Kugelrohr) was accomplished in a Sibata GTO-250RS at the oven temperature and pressure indicated. Yields were determined by GLC or ^{1}H NMR using internal standards.

General Procedure for Synthesis of Homoallyl Silyl Ether (3). Chlorotrimethylsilane (2.0 mmol) was added to a stirred solution of diallyldibutyltin (**1**) (1.0 mmol) and carbonyl compound **2** (2.0 mmol) in dry acetonitrile (2 mL) and the mixture was stirred at ambient temperature for 1 h. Diethyl ether and aqueous NH_4F (15%) were added, and the organic layer was separated and washed with water, dried ($MgSO_4$) and evaporated. The crude product was purified by distillation to give the homoallyl silyl ether **3**.

4-(Trimethylsiloxy)-4-phenyl-1-butene (3a). Obtained from **1** and **2a** according to the general procedure by distillation (65 °C/0.1 mmHg): IR (neat) 1650 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36-7.21 (m, 5H), 5.77 (ddt, 1H, J = 17.09, 10.26, 7.09 Hz), 5.03 (d, 1H, J = 17.09 Hz), 5.01 (d, 1H, J = 10.26 Hz), 4.66 (dd, 1H, J = 7.09, 5.38 Hz), 2.51-2.38 (m, 2H), 0.04 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 144.7, 134.1, 127.9, 126.9, 125.8, 116.7, 74.9, 45.16, 0.16; MS m / z 221 (M^+ + 1), 179 (M^+ - 41); HRMS calcd for $C_{13}H_{21}OSi$ 221.1362, found m / z 221.1375 (M^+ + 1).

4-(Trimethylsiloxy)-5-phenyl-1-pentene (3b). Obtained from **1** and **2b** according to the general procedure by distillation (70 °C/0.1 mmHg): IR (neat) 1640 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44-7.08 (m, 5H), 6.03-5.92 (m, 1H), 5.40-5.16 (m, 2H), 4.03-3.78 (m, 1H), 2.89 (dd, 1H, J = 13.18, 4.88 Hz), 2.78 (dd, 1H, J =

13.18, 7.81 Hz), 2.48-2.30 (m, 2H), 0.04 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 139.0, 135.0, 129.5, 127.8, 125.8, 116.8, 73.5, 43.7, 42.0, -0.03; MS *m / z* 235 (M^+ + 1), 193 (M^+ - 41); HRMS calcd for $C_{14}H_{23}OSi$ 235.1518, found *m / z* 235.1499 (M^+ + 1).

4-(Trimethylsiloxy)-5-phenyl-1-hexene (3c). Obtained from **1** and **2c** according to the general procedure by distillation (70 °C/0.1 mmHg): IR (neat) 1640 cm^{-1}; MS *m / z* 249 (M^+ + 1), 207 (M^+ - 41); HRMS calcd for $C_{15}H_{25}OSi$ 249.1674, found *m / z* 249.1683 (M^+ + 1): Major product; ^1H NMR (400 MHz, $CDCl_3$) δ 7.29-7.16 (m, 5H), 5.87-5.74 (m, 1H), 5.05-4.95 (m, 2H), 3.77 (td, 1H, *J* = 6.02, 6.02 Hz), 2.79 (qd, 1H, *J* = 6.83, 6.83 Hz), 2.21-2.14 (m, 2H), 1.26 (d, 3H, *J* = 7.32 Hz), 0.01 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 144.9, 135.1, 128.0, 127.9, 126.0, 116.8, 77.0, 44.8, 40.0, 16.3, 0.37: Minor product; ^1H NMR (400 MHz, $CDCl_3$) δ 7.29-7.16 (m, 5H), 5.87-5.74 (m, 1H), 5.05-4.95 (m, 2H), 3.77 (td, 1H, *J* = 6.02, 6.02 Hz), 2.80 (qd, 1H, *J* = 6.84, 6.84 Hz), 2.08-2.01 (m, 2H), 1.25 (d, 3H, *J* = 7.33 Hz), -0.05 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 144.2, 135.4, 128.4, 127.8, 126.0, 116.6, 77.0, 45.1, 39.3, 17.4, 0.25.

4-(Trimethylsiloxy)-6-phenyl-1,5-hexadiene (3d). Obtained from **1** and **2d** according to the general procedure by distillation (68 °C/0.1 mmHg): IR (neat) 1640 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.42-7.09 (m, 5H), 6.43 (d, 1H, *J* = 16.11 Hz), 6.12 (dd, 1 H, *J* = 16.11, 6.35 Hz), 5.82-5.61 (m, 1H), 5.14-4.80 (m, 2H) 4.23 (dt, 1H, *J* = 6.02, 6.02 Hz), 2.38-2.22 (m, 2H), 0.07 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ

136.9, 134.7, 132.4, 129.3, 128.4, 127.3, 126.3, 116.9, 73.2, 42.9, 0.04; MS *m / z* 246 (M^+), 205 (M^+ - 41); HRMS calcd for $C_{15}H_{22}OSi$ 246.1440, found *m / z* 246.1455 (M^+).

4-(Trimethylsiloxy)-1-octene (3e). Obtained from **1** and **2e** according to the general procedure by distillation (90 °C/20 mmHg): IR (neat) 1640 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 5.79-5.68 (m, 1H), 5.14-4.75 (m, 2H), 3.59 (qu, 1H, *J* = 5.86 Hz),

2.18-2.05 (m, 2H), 1.43-1.12 (m, 6H), 0.82 (t, 3H, J = 6.84 Hz), 0.04 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 135.3, 116.5, 72.3, 42.3, 36.7, 27.9, 22.8, 14.1, 0.5; MS m / z 201 (M^+ + 1), 159 (M^+ - 41); HRMS calcd for $C_{11}H_{25}OSi$ 201.1674, found m / z 201.1660 (M^+).

5,5-Dimethyl-4-(trimethylsiloxy)-1-hexene (3f). Obtained from **1** and **2f** according to the general procedure by distillation (90 °C/20 mmHg): IR (neat) 1640 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 5.82 (ddt, 1H, J = 17.09, 10.25, 6.84 Hz), 5.06-5.00 (m, 2H), 3.31 (dd, 1H, J = 8.79, 2.93 Hz), 2.28 (ddddd, 1H, J = 14.16, 6.87, 2.93, 1.47 Hz), 2.06 (ddd, 1H, J = 14.16, 8.79, 6.84 Hz), 0.86 (s, 9H), 0.09 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 136.5, 115.1, 80.1, 36.7, 34.6, 25.4, 0.0; MS m / z 159 (M^+ - 41); HRMS calcd for $C_{11}H_{23}OSi$ 199.1518, found m / z 199.1496 (M^+ - 1); Anal. Calcd for $C_{11}H_{24}OSi$: C, 65.93; H, 12.07. Found: C, 65.63; H, 12.37.

1-(Trimethylsiloxy)-1-(2-propenyl)cyclohexane (3g). Obtained from **1** and **2g** according to the general procedure by distillation (125 °C/24 mmHg): IR (neat) 1640 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 5.79 (ddt, 1H, J = 17.09, 10.26, 7.09 Hz), 4.97 (dd, 1H, J = 10.26, 0.98 Hz), 4.95 (dd, 1H, J = 17.09, 1.47 Hz), 2.19 (dd, 1H, J = 7.09, 1.47 Hz), 1.54-1.19 (m, 11H), 0.06 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 134.9, 116.7, 75.3, 46.3, 38.0, 25.9, 22.6, 2.83; MS m / z 212 (M^+), 171 (M^+ - 41); HRMS calcd for $C_{12}H_{24}OSi$ 212.1596, found m / z 212.1584 (M^+).

4-(Trimethylsiloxy)-4-phenyl-1-pentene (3h). Obtained from **1** and **2h** according to the general procedure by distillation (45 °C/0.1 mmHg): IR (neat) 1640 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.47-7.17 (m, 5H), 5.63 (ddt, 1H, J = 17.09, 10.25, 7.09 Hz), 5.00-4.91 (m, 2H), 2.53 (dd, 1H, J = 13.92, 7.09 Hz), 2.46 (dd, 1H, J = 13.92, 7.09 Hz), 1.61 (s, 3H), 0.08 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 148.3, 134.8, 127.8, 126.4, 125.3, 117.1, 77.2, 50.5, 28.5, 2.4; MS m / z 235 (M^+ + 1), 193 (M^+ - 41); HRMS calcd for $C_{14}H_{23}OSi$ 235.1518, found m / z 235.1535 (M^+ + 1).

4-(Trimethylsiloxy)-4-(2-thienyl)-1-butene (3i). Obtained from **1** and **2i** according to the general procedure by distillation (50 °C/3 mmHg): IR (neat) 1640 cm^{-1};

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.20-6.88 (m, 3H), 5.78 (ddt, 1H, *J* = 17.58, 10.25, 7.09 Hz), 5.20 (d, 1H, *J* = 17.58 Hz), 5.17 (d, 1H, *J* = 10.25 Hz),4.95 (dd, 1H, *J* = 7.08, 6.11 Hz), 2.65-2.47 (m, 2H), 0.08 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 149.1, 134.5, 126.1, 123.8, 122.8, 117.2, 70.8, 45.2, 0.09; MS *m* / *z* 227 (M^+ + 1), 185 (M^+ - 41); HRMS calcd for $C_{11}H_{19}OSSi$ 227.0926, found *m* / *z* 227.0922 (M^+ + 1); Anal. Calcd for $C_{11}H_{18}OSSi$: C, 58.35; H, 8.01. Found: C, 58.54; H, 7.89.

4-(Trimethylsiloxy)-4-(*p*-bromophenyl)-1-butene (3j). Obtained from **1** and **2j** according to the general procedure by distillation (88 °C/3 mmHg): IR (neat) 1640 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46-7.17 (m, 4H), 5.76-5.69 (m, 1H), 5.05-4.99 (m, 2H), 4.63 (dd, 1H, *J* = 7.09, 5.62 Hz), 2.45-2.35 (m, 2H), 0.04 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 143.7, 135.0, 131.0, 127.5, 120.6, 117.1, 74.1, 44.9, 0.09; MS *m* / *z* 301 (M^+ + 3), 299 (M^+ + 1), 259 (M^+ - 39), 257 (M^+ - 41); HRMS calcd for $C_{13}H_{20}OBrSi$ 299.0467, found *m* / *z* 299.0479 (M^+ + 1); Anal. Calcd for $C_{13}H_{19}OBrSi$: C, 52.17; H, 6.40. Found: C, 51.68; H, 6.24.

1-[(1-Trimethylsiloxy)-3-butenyl]-4-isopropenylcyclohexene (3k). Obtained from **1** and **2k** according to the general procedure by distillation (75 °C/3 mmHg): IR (neat) 1640 cm^{-1}; MS *m* / *z* 265 (M^+ + 1), 223 (M^+ - 41); HRMS calcd for $C_{16}H_{29}OSi$ 265.1988, found *m* / *z* 265.1975 (M^+ + 1): Major product; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.78 (ddt, 1H, *J* = 17.09, 10.25, 7.09 Hz), 5.61-5.58 (m, 1H), 5.03 (d, 1H, *J* = 17.09 Hz), 5.00 (d, 1H, *J* = 10.25 Hz), 4.73-4.70 (m, 2H), 3.99 (t, 1H, *J* = 6.84 Hz), 2.34-1.45 (m, 9H), 1.14 (s, 3H), 0.09 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 150.0, 139.3, 135.6, 122.5, 116.2, 108.5, 76.7, 41.2, 40.7, 30.6, 27.5, 24.0, 20.8, 0.17; Minor product; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.75 (ddt, 1H, *J* = 17.09, 10.25, 7.09 Hz), 5.72-5.70 (m, 1H), 5.17-5.09 (m, 2H), 4.73-4.70 (m, 2H), 4.05 (t, 1H, *J* = 6.59 Hz), 2.34-1.45 (m, 9H), 1.14 (s, 3H), 0.09 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 149.8, 139.1, 135.7, 121.7, 116.1, 108.6, 76.7, 41.5, 40.9, 30.3, 27.6, 23.3, 20.8, 1.32.

1,4-Bis(1-trimethylsiloxy-3-butenyl)benzene (3l). Obtained from **1** and

2l according to the general procedure by distillation (120 °C/0.1 mmHg): IR (neat) 1640 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 7.30-7.23 (m, 4H), 5.75 (ddt, 1H, *J* = 17.09, 10.25, 6.84 Hz), 5.01 (d, 1H, *J* = 17.09 Hz), 5.00 (d, 1H, *J* = 10.25 Hz), 4.64 (dd, 1H, *J* = 7.81, 5.37 Hz), 2.49-2.37 (m, 2H), 0.01 (s, 9H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 143.6, 135.4, 125.8, 116.7, 74.8, 45.0, 0.13; MS *m / z* 363 (M^+ + 1), 321 (M^+ - 41); HRMS calcd for $C_{20}H_{35}O_2Si_2$ 363.2176, found *m / z* 363.2166 (M^+ + 1); Anal. Calcd for $C_{20}H_{34}O_2Si_2$: C, 66.24; H, 9.45. Found: C, 66.44; H, 9.38.

Phthalan derivative (4). Obtained from **1** and **2m** according to the general procedure by distillation (75 °C/0.1 mmHg): IR (neat) 1640 cm^{-1}; MS *m / z* 201 (M^+ + 1), 159 (M^+ - 41); HRMS calcd for $C_{14}H_{15}O$ 199.1123, found *m / z* 199.1103 (M^+ - 1): Major product; ^1H NMR (400 MHz, $CDCl_3$) δ 7.29-7.16 (m, 4H), 5.83 (ddt, 2H, *J* = 17.09, 10.25, 6.84 Hz), 5.32 (t, 2H, *J* = 4.88 Hz), 5.12 (d, 2H, *J* = 17.09 Hz), 5.07 (d, 2H, *J* = 10.25 Hz), 2.67-2.48 (m, 4H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 141.8, 134.0, 127.4, 121.4, 117.7, 82.4, 41.0: Minor product; ^1H NMR (400 MHz, $CDCl_3$) δ 7.29-7.16 (m, 4H), 5.89 (ddt, 2H, *J* = 17.09, 10.25, 6.84 Hz), 5.23 (t, 2H, *J* = 5.62 Hz), 5.15 (d, 2H, *J* = 17.09 Hz), 5.10 (d, 2H, *J* = 10.25 Hz), 2.67-2.48 (m, 4H); ^{13}C NMR (22.6 MHz, $CDCl_3$) δ 141.8, 134.3, 127.5, 121.4, 117.5, 82.3, 40.3.

4-4 References and Notes

1. M. Pereyre, J.-P. Quintard, and A. Rahm, *Tin in Organic Synthesis*, Butterworths, London, 1987.
2. Y. Nishigaichi, A. Takuwa, Y. Naruta, and K. Maruyama, *Tetrahedron*, **49**, 7395 (1993).
3. Y. Yamamoto and N. Asao, *Chem. Rev.*, **93**, 2207 (1993).
4. (a) E. J. Corey and N. W. Boaz, *Tetrahedron Lett.*, **26**, 6015, 6019 (1985). (b) E. Nakamura, S. Matsuzawa, Y. Horiguchi, and I. Kuwajima, *Tetrahedron Lett.*, **27**, 4029 (1986). (c) A. Alexakis, J. Berlan, and Y. Besace, *Tetrahedron Lett.*, **27**, 1047 (1986).

5. (a) H. Oshino, E. Nakamura, and I. Kuwajima, *J. Org. Chem.*, **50**, 2802 (1985). (b) E. Nakamura, S. Aoki, K. Sekiya, H. Oshino, and I. Kuwajima, *J. Am. Chem. Soc.*, **109**, 8056 (1987).
6. N. Iwasawa and T. Mukaiyama, *Chem. Lett.*, **1987**, 463.
7. T. Yura, N. Iwasawa, and T. Mukaiyama, *Chem. Lett.*, **1987**, 791.
8. M. Bergdahl, M. Eriksson, M. Nilsson, and T. Olsson, *J. Org. Chem.*, **58**, 7238 (1993).
9. 5 mL of solvent was used because of low solubility of LiCl although it did not dissolve completely.
10. G. A. Olah, S. C. Narang, B. G. B. Gupta, and R. Malhotra, *J. Org. Chem.*, **44**, 1247 (1979).
11. S. Matsuzawa, Y. Horiguchi, E. Nakamura, and I. Kuwajima, *Tetrahedron*, **45**, 349 (1989).
12. The trapping by Me_3SiCl in a conjugate alkylation has been reported,[4] where an addition could take place even in the absence of it.

Conclusion

The aims of this research were to control the selective reactions using highly coordinated organotin compounds. The results obtained from the present work are summarized as follows.

In chapter 1, synthesis of 1,4-diketones from tin enolate and α-bromo ketones in the presence of appropriate additives such as HMPA, Bu_3PO and Bu_4NBr is described. It is also found that this reaction system can be applied to coupling with α-bromo ester and α-bromo aldehyde as electrophiles. This reactions proceed in a manner of a direct substitution at a halide moiety in α-halo carbonyls.

In chapter 2, NMR studies of tin enolates in the presence of HMPA are carried out. The addition of HMPA causes the formation of a five-coordinate *O*-stannyl enolate which contributes to upfield shifts of Sn peaks in the ^{119}Sn NMR spectrum and increased coupling constants J (^{119}Sn-^{13}C), compared with the four-coordinate tin enolate. The tautomeric equilibrium between *C*-stannyl ketone and *O*-stannyl enolate was changed by the addition of HMPA, the percentage of enol form being increased. The resulting five-coordinate tin enolates showed high reactivity and selectivity for halide displacement in reactions with α-halo ketones. The tin enolates, when coordinated by Bu_4NBr, effected a selective reaction with α-halo imines to give a variety of γ-imino ketones, which were subsequently hydrolysed to 1,4-diketones, or cyclodehydrated to substituted pyrroles.

In chapter 3, the selective addition of tin enolates to the carbonyl moiety in α-halo ketones using two types of catalysts, five-coordinate organotin bromides and tetraphenylstibonium bromide, is described. The reaction with 2-chlorocyclohexanones and the enolates gave the chlorohydrins bearing chloro- and hydroxyl groups in *cis*-conformation. The chemoselective carbonyl addition to acyclic α-halo ketones was followed by effective cyclization to β-keto oxiranes. The structural and bonding analogy of the both catalysts may be responsible for the similar catalytic activities which induced the chemo- and stereoselective additions.

In chapter 4, the combination of chlorotrimethylsilane and acetonitrile is found to be a new promoter for carbonyl allylation by diallyldibutyltin. This reaction system affords a variety of homoallyl silyl ether in good yields.

Finally, highly coordinated organotin compounds prove to be useful for the selective reactions. Several important features obtained through the present investigations would develop the new field of synthetic organotin chemistry.